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Measuring Adhesion Using Fiber Bragg Gratings

C1C Noah T Blach

U.S. DEPARTMENT OF ENERGY | National Nuclear Security Administration

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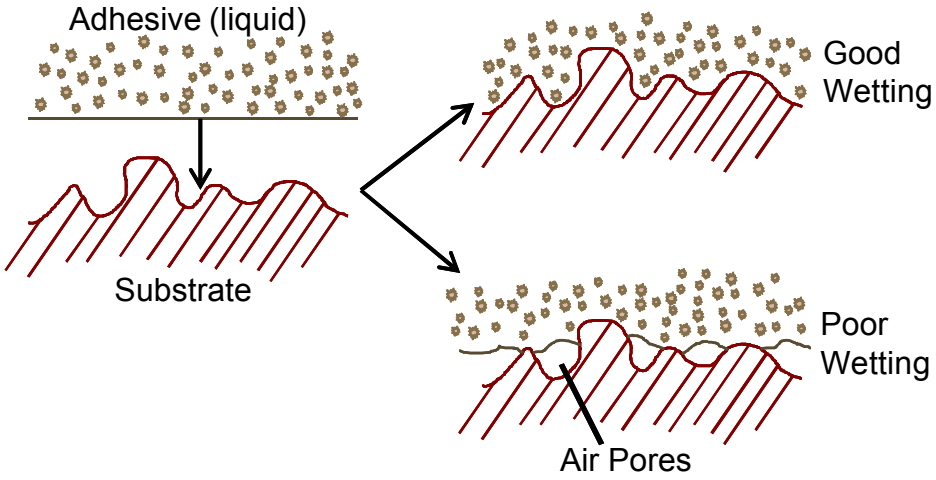
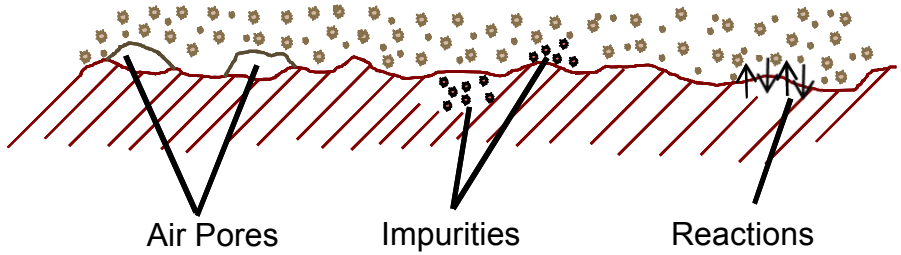
Detection of Weak Bonds

Mechanical Interlocking Model



Weak Boundary Layer Model



Technical Problem

- **Debonds and adhesive failures at interfaces are poorly characterized or identifiable**

Yang, S.; Gu, L.; Gibson, R. F. *Compos. Struct.* **2001**, *51*, 63.
Nagy, P. B. *Journal of Nondestructive Evaluation* **1992**, *11*, 127.
Kumar, R. L. V.; Bhat, M. R.; Murthy, C. R. L. *Int. J. Adhes. Adhes.* **2013**, *42*, 60.
Vine, K.; Cawley, P.; Kinloch, A. J. *J. Adhes.* **2001**, *77*, 125.

NDI Inspection Methods

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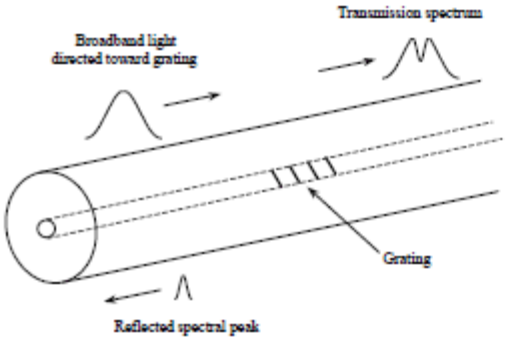
- **Time Domain Ultrasonics**: Monitor the ultrasonic echoes in the time domain.
  - If a defect exists, the local reflection coefficient will be changed. And so is the ultrasonic echo.
- **Ultrasonic Impedance and Spectroscopy**: Measures the characteristics of through-thickness vibration of a bonded structure.
  - Any changes in adhesive or adherend will result in amplitudes and resonance that are different from the undamaged structure.
- **Sonic Vibration**: Monitor vibration properties of a bonded structure.
  - Any defect will cause a local change in stiffness and thus vibration behavior to the whole structure.
- **Vibrothermography**: Monitor the surface temperature of a component as it is cyclically stressed.
  - A defect will cause a local rise in temperature due to either frictional heating at its internal surfaces or hysteretic energy dissipation. Use infrared thermal imaging camera.
- **Thermography**: Measure the response of the specimen to thermal transients created by an external heat source.
  - For example, heat the back surface of the structure and defects can be found by measuring temperature changes at front since defective areas are cooler due to the lower conduction through defects.

Many advantages, however the ability to reliably detect weak bonds is debatable!!!

Hart-Smith, L. J. *J. Compos. Technol. Res.* **2002**, *24*, 133.
Yang, S.; Gu, L.; Gibson, R. F. *Compos. Struct.* **2001**, *51*, 63.

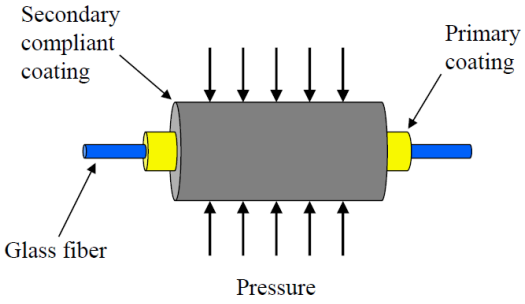
Fiber Bragg Grating Sensor Design

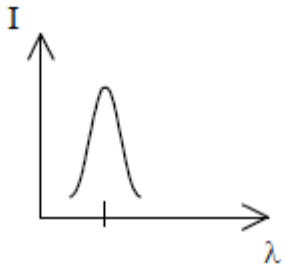


As the fiber undergoes tension & compression, the grating spacing changes

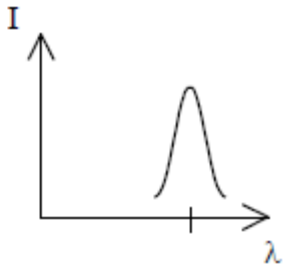
Grating spacing d_1

Grating spacing d_2





Reflected peak at lower center wavelength



Reflected peak at higher center wavelength

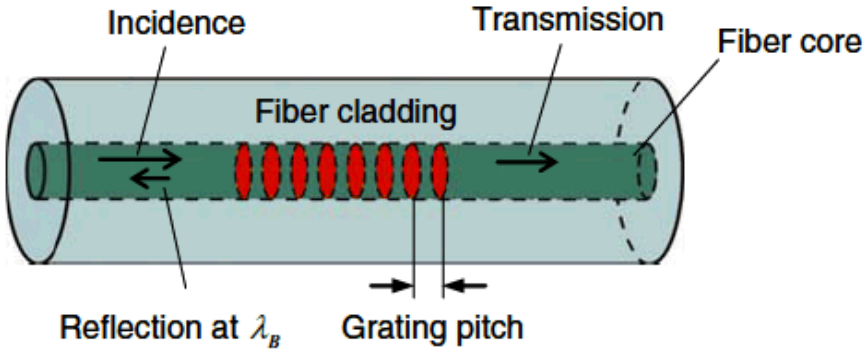
Grating spacing changes as the fiber goes through any tension or compression

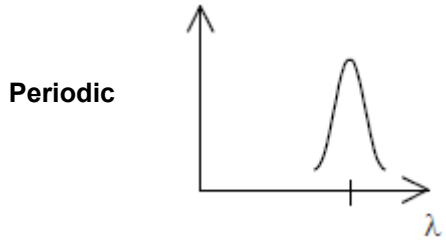
Advantages: 1) Inexpensive, 2) Facile, 3) Spatial dimension, 4) Regions/Area, 5) Continuous

Udd, Eric. Review of Multi-Parameter Fiber Grating Sensors. Columbia Gorge Research, LLC.

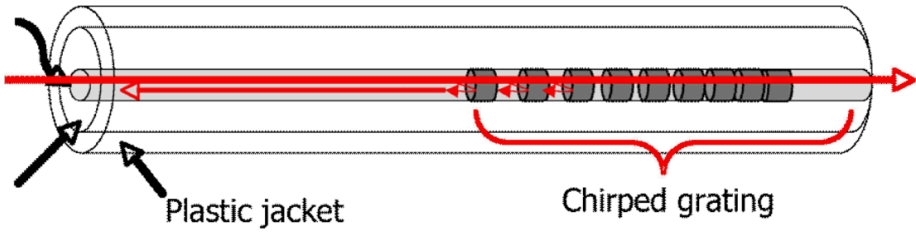
Grating Type

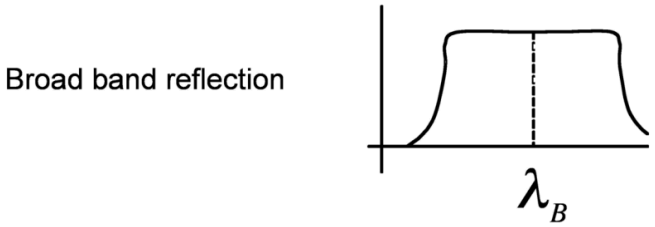
FBG





Chirped FBG



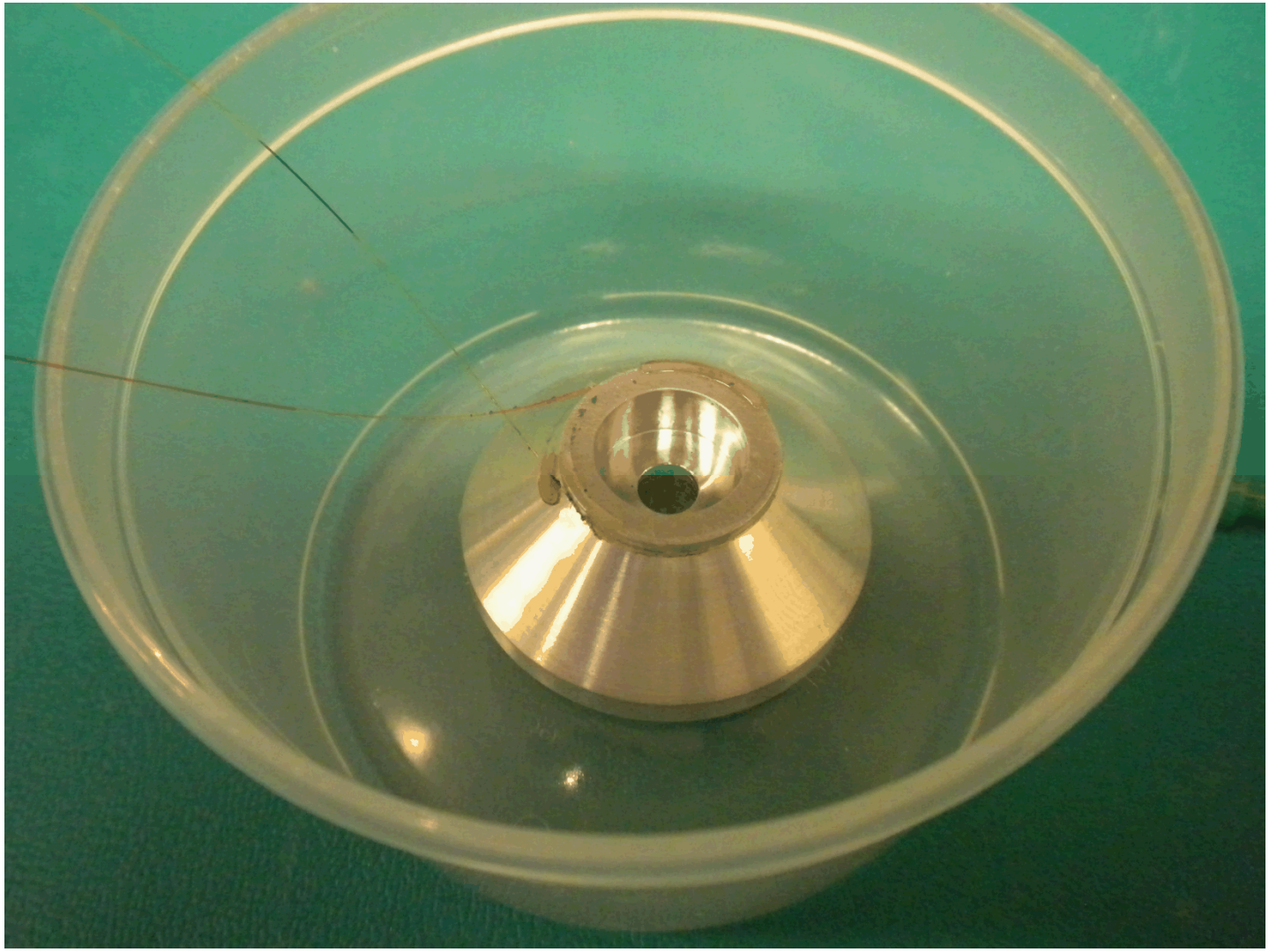


Fiber Bragg Gratings are periodic whereas chirped gratings are graduated and exhibit broadband reflectance.

$$\frac{1\ nm}{1200\ \mu\varepsilon}\ at\ 1.55\ \mu m$$

Wang, Y.; Han, B.; Kim, D. W.; Bar-Cohen, A.; Joseph, P. *Exp. Mech.* **2008**, *48*, 107.
Udd, E.; Benterou, J.; May, C.; Mihailov, S. J.; Lu, P. In *Fiber Optic Sensors and Applications Vii*; Mendez, A., Du, H. H., Wang, A., Udd, E., Mihailov, S. J., Eds.; Spie-Int Soc Optical Engineering: Bellingham, 2010; Vol. 7677.

Mounted cone



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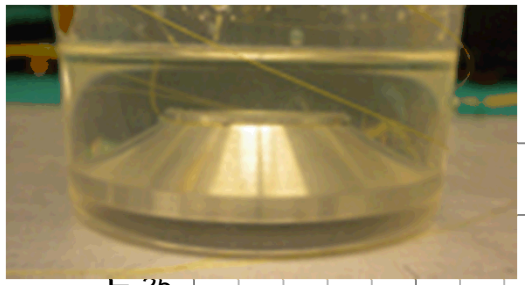
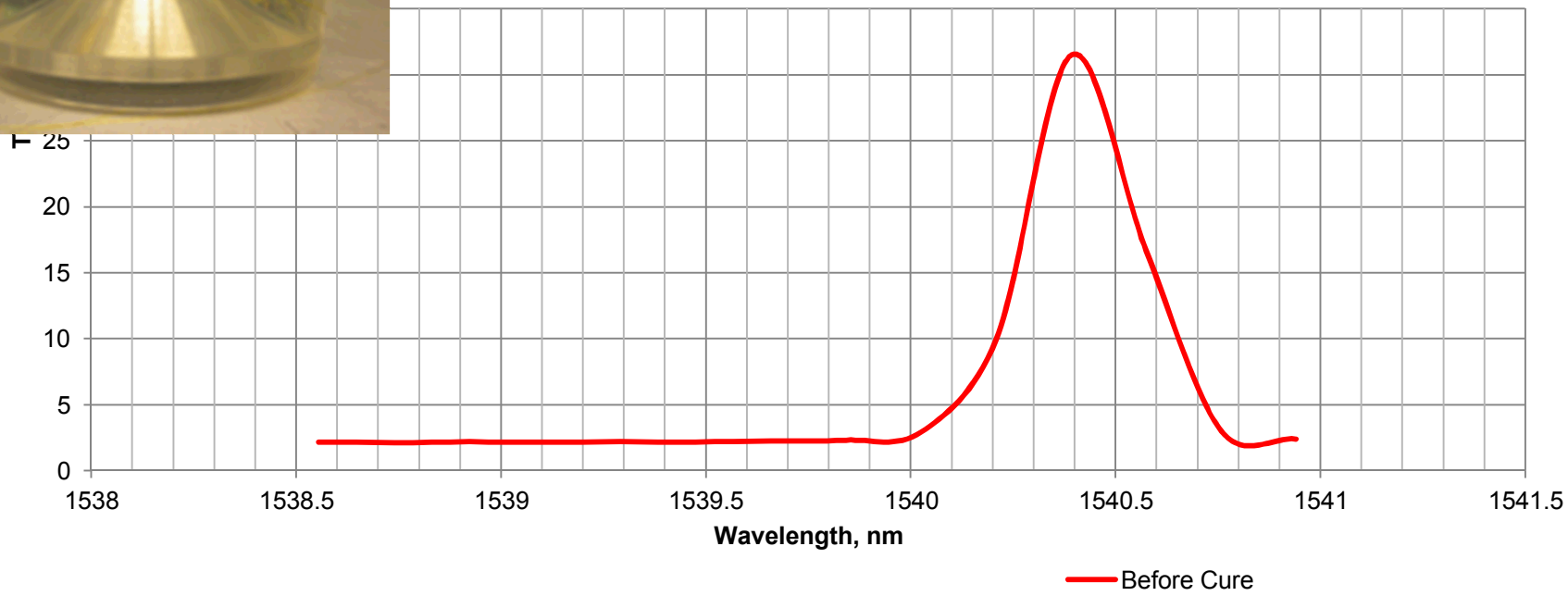
Single Grating Demonstration





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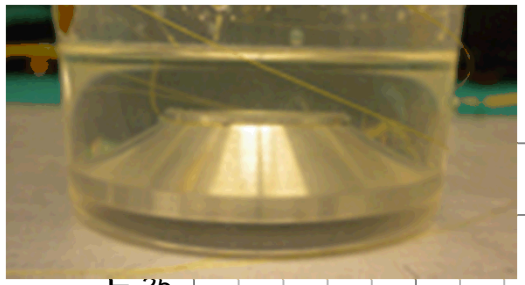
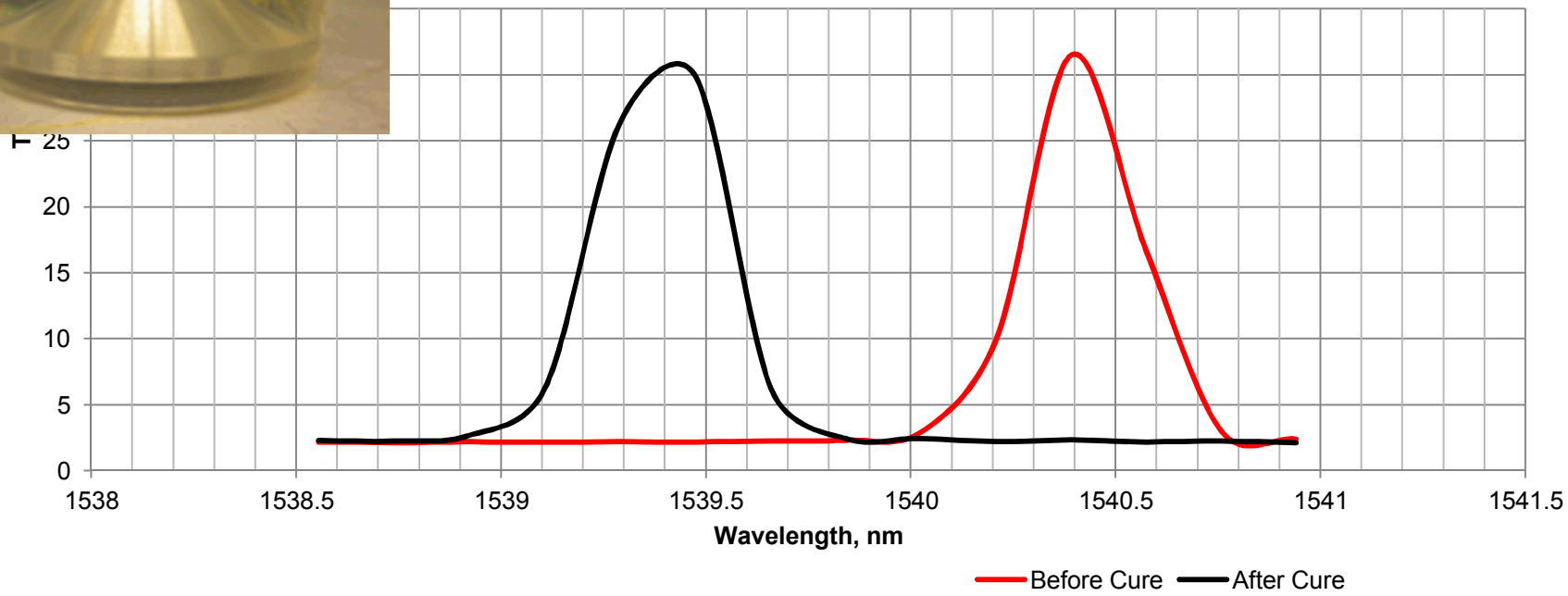
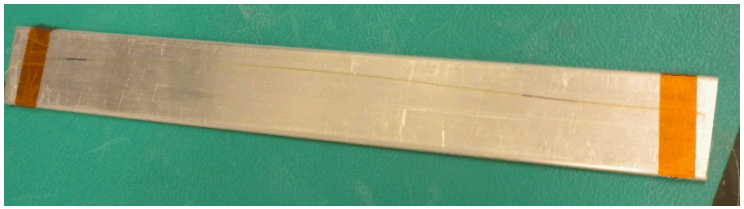
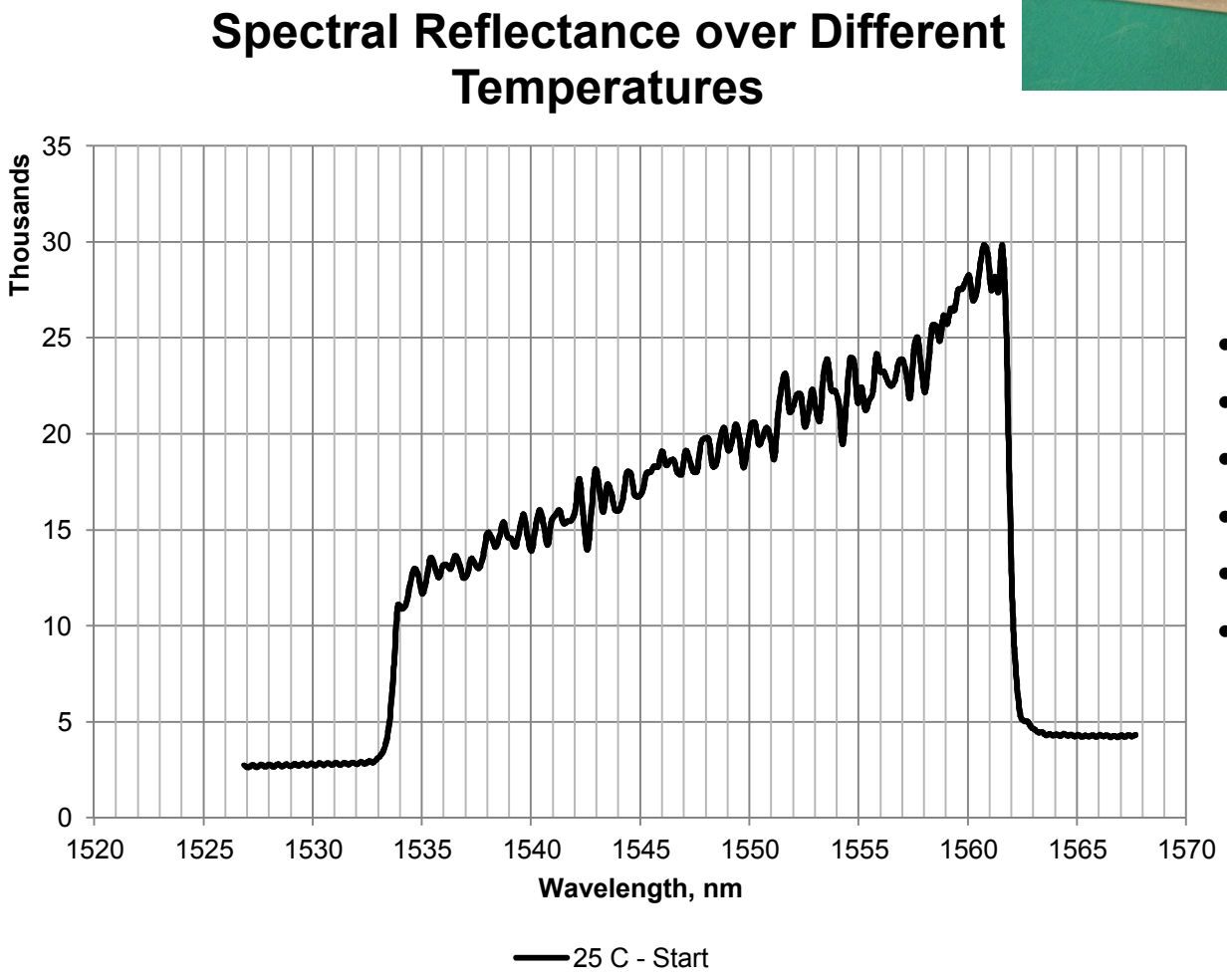




Shift of 1 nm = 1200με

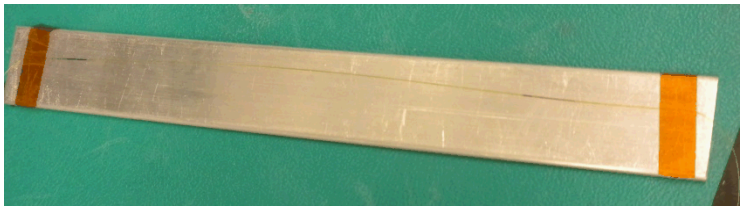
Thermally Cycled Fiber- Unmounted

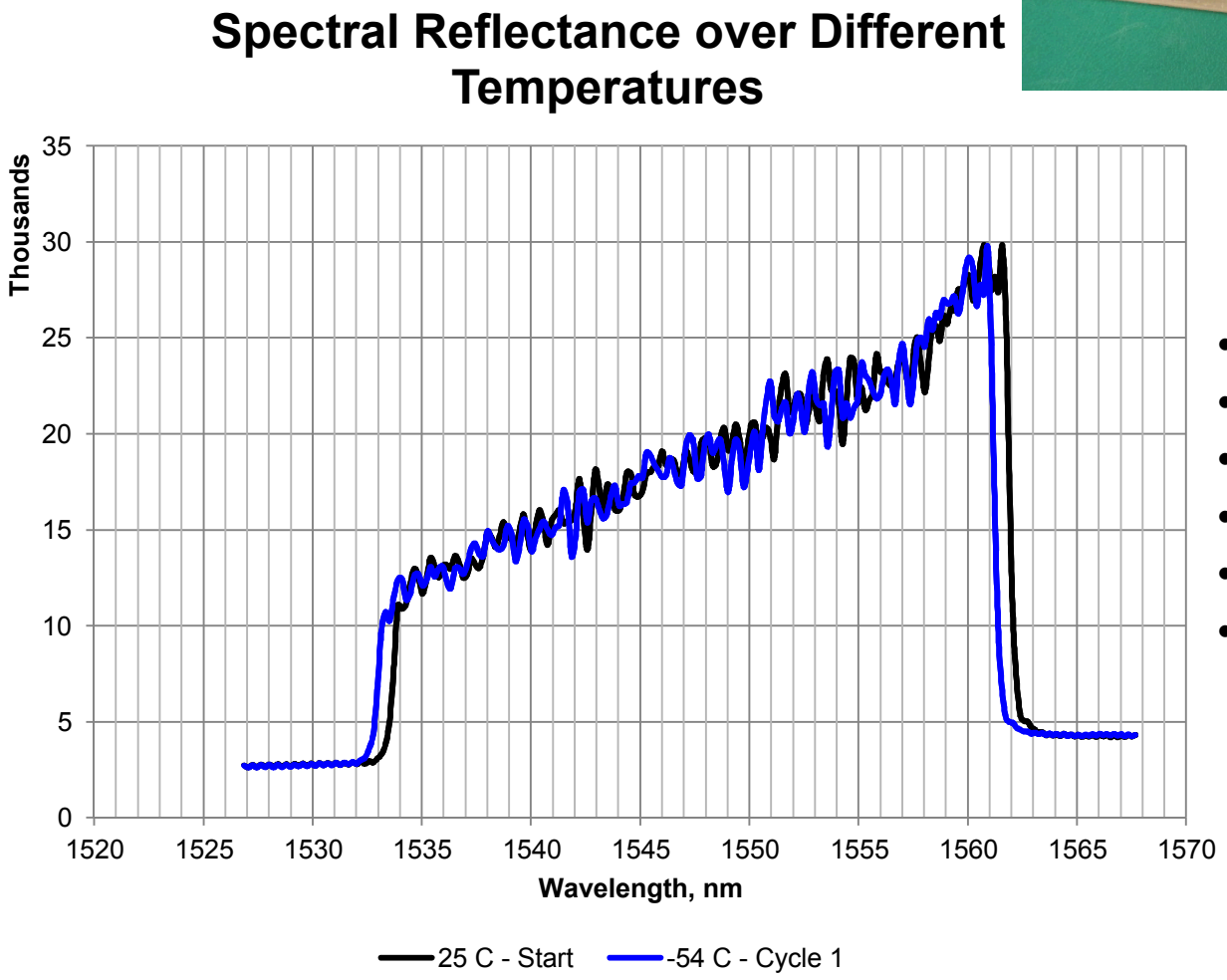




- 25 C for 20 Minutes
- -54 C for 120 Minutes
- 25 C for 20 Minutes
- 71 C For 120 Minutes
- Repeated 3 times
- All ramp rates 5 C/Minute

Thermally Cycled Fiber- Unmounted





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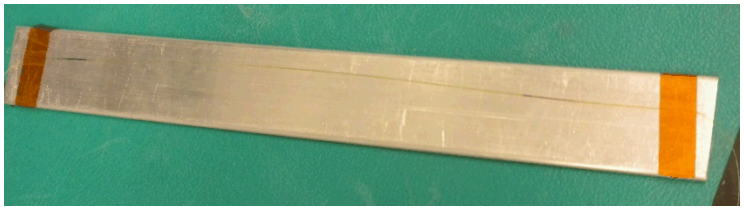

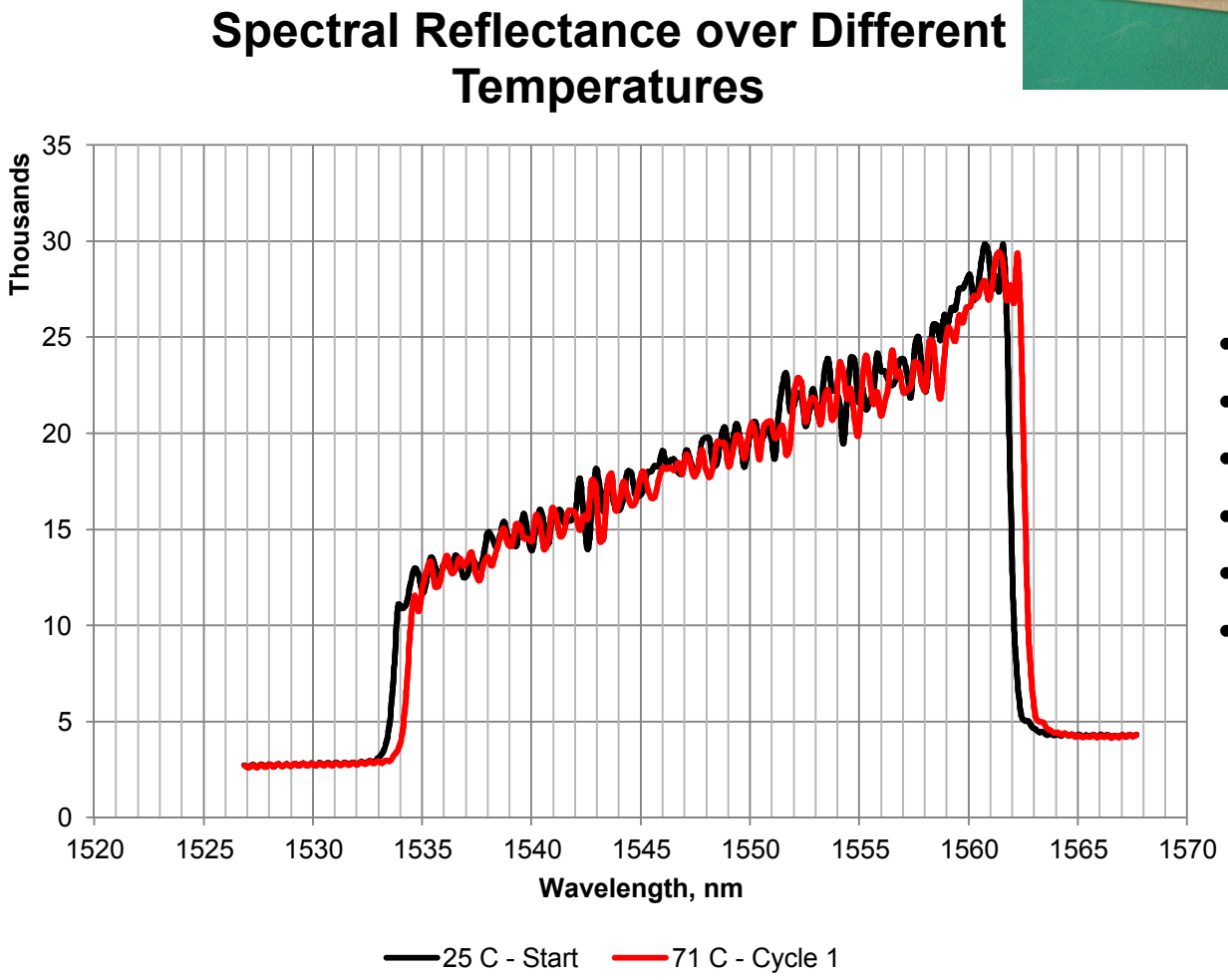

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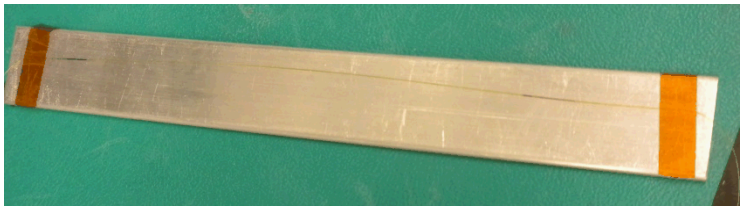

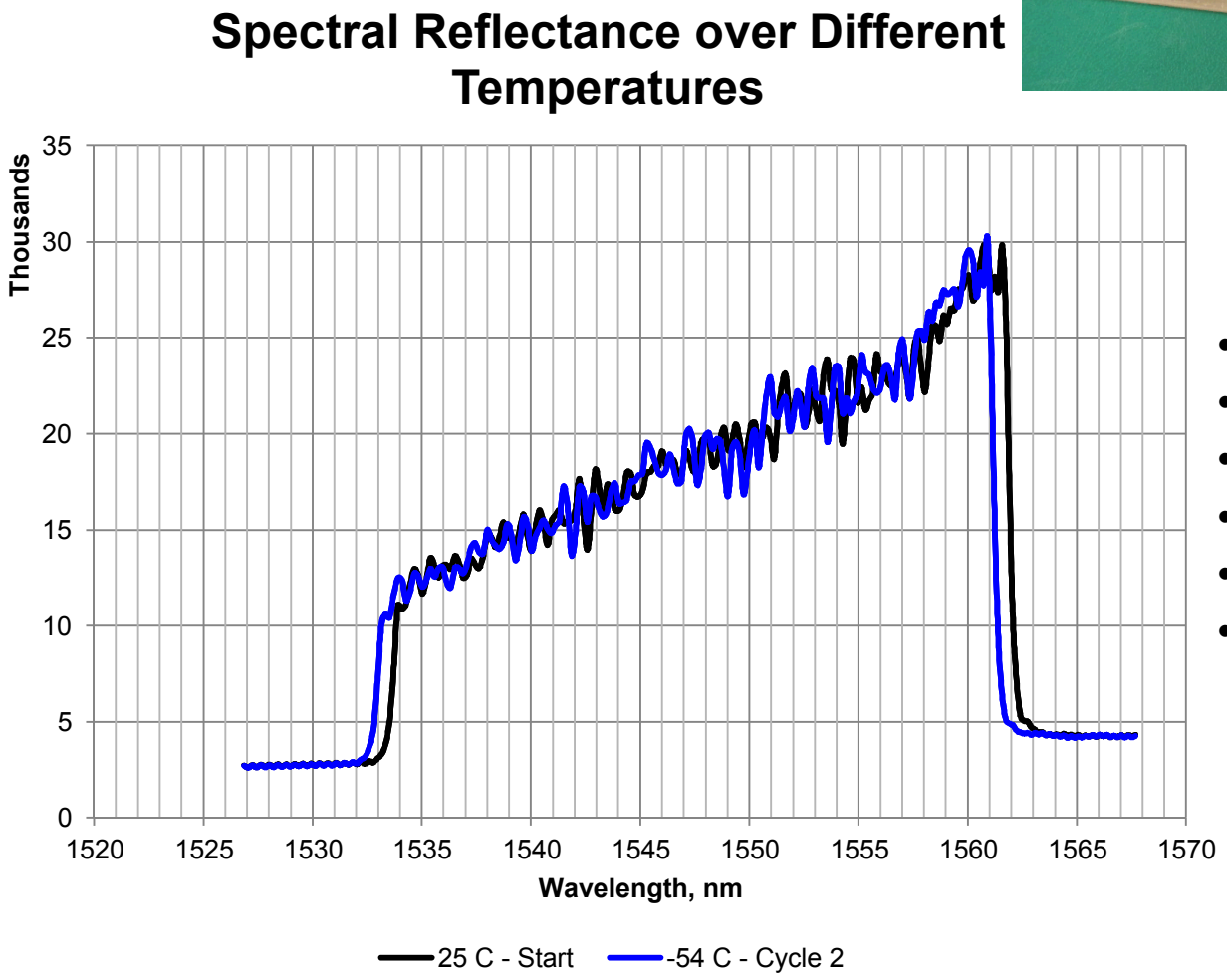

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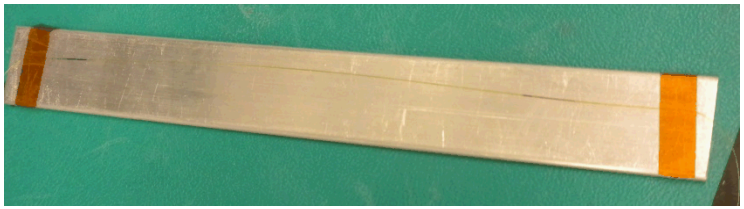

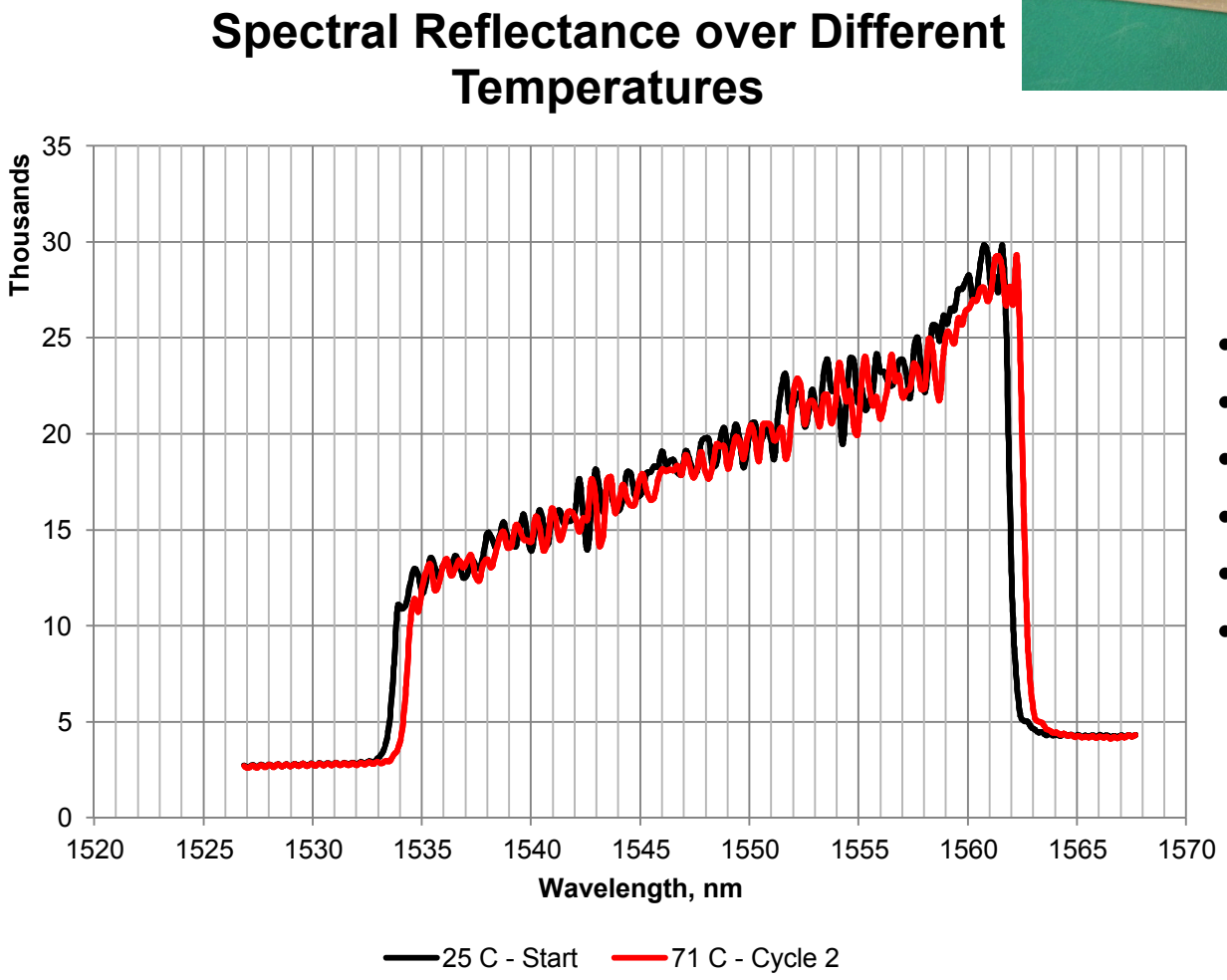

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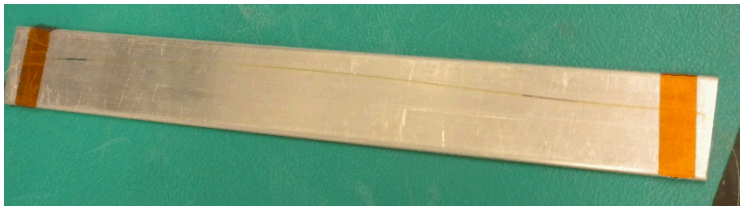

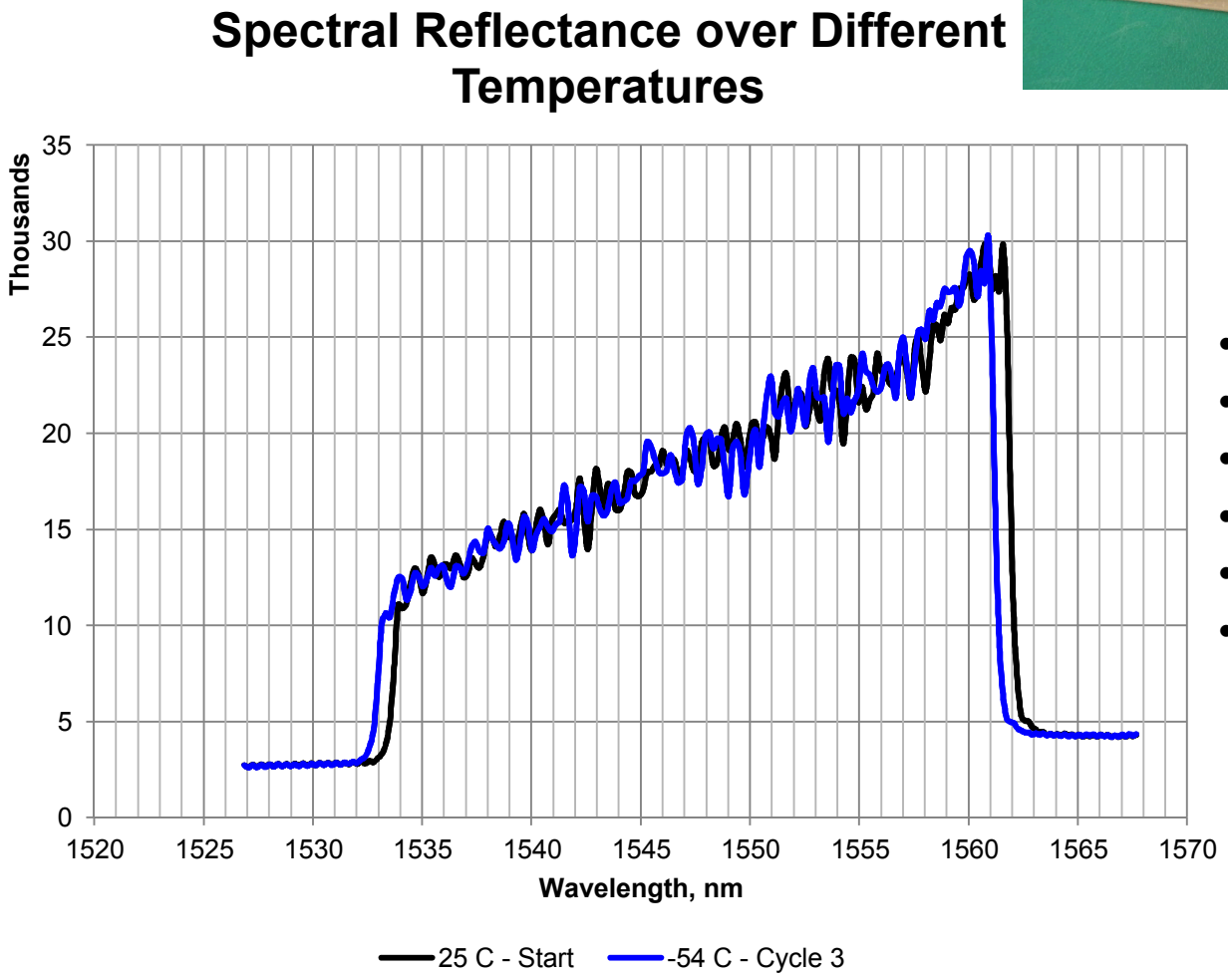

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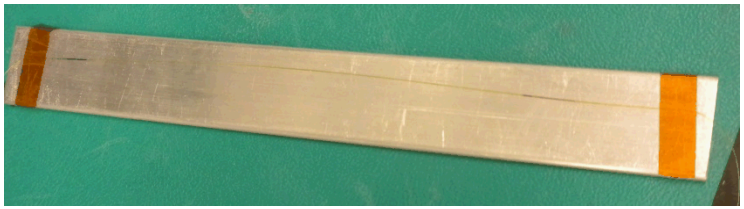

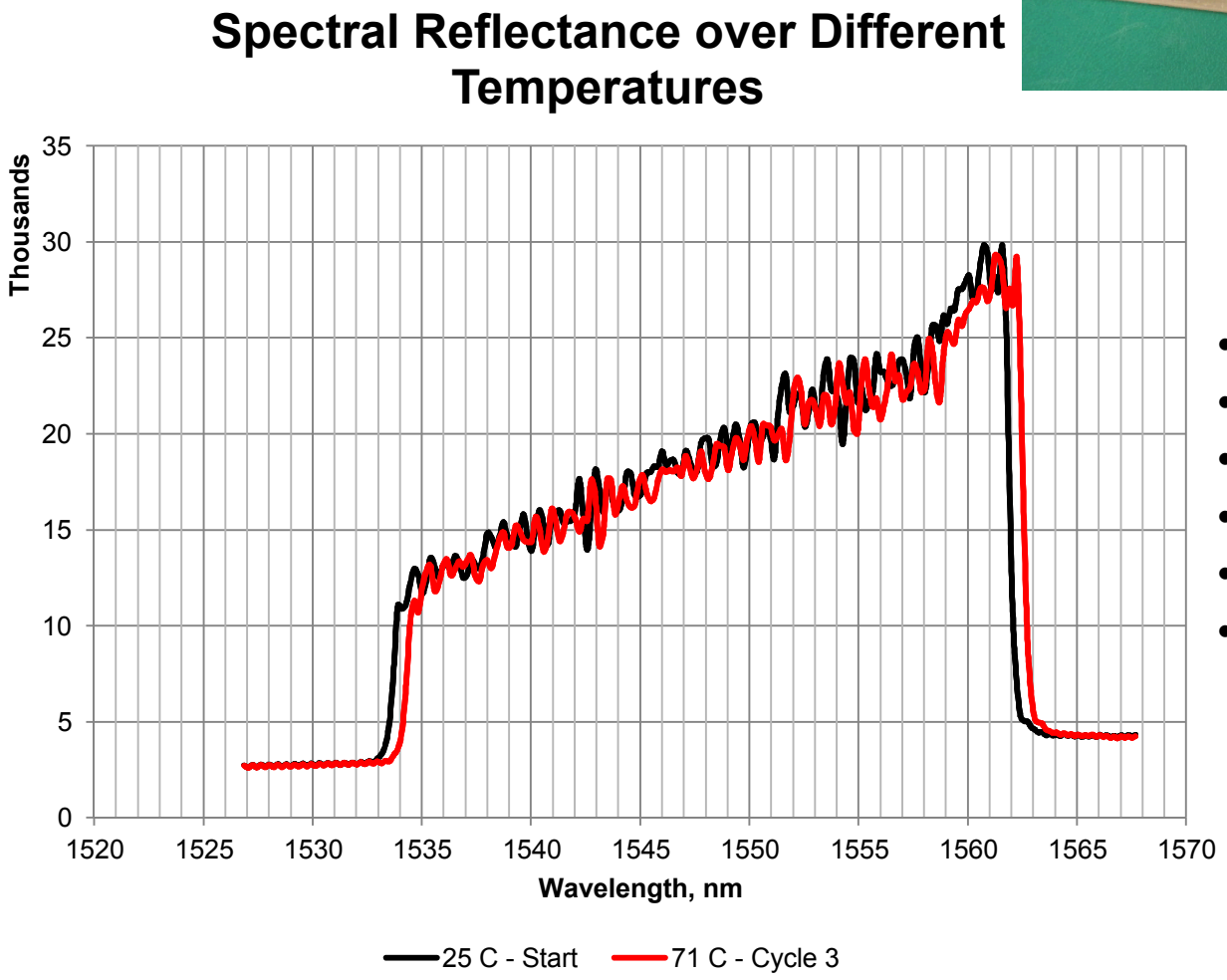

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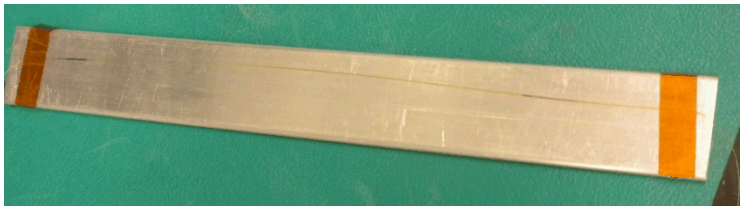

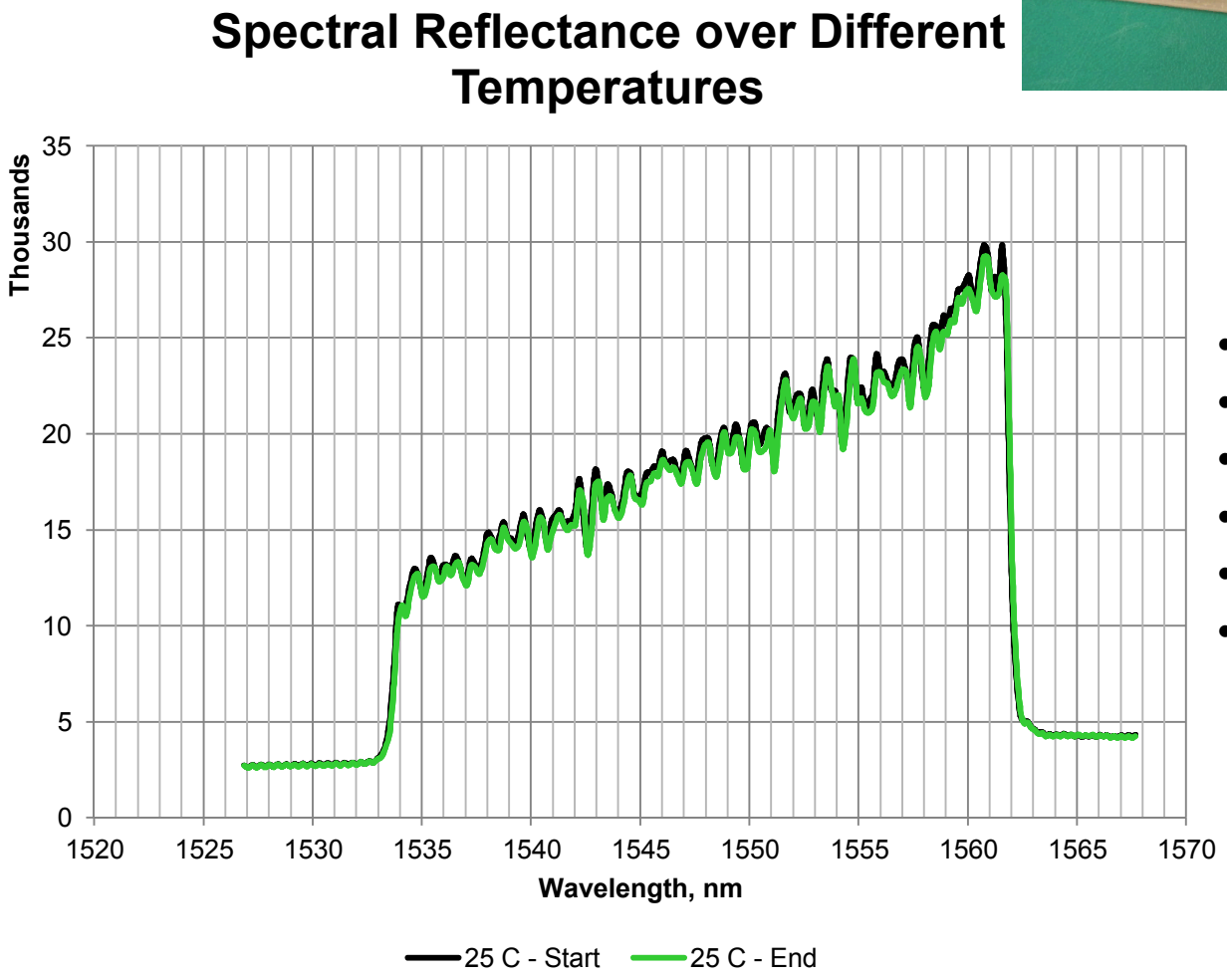

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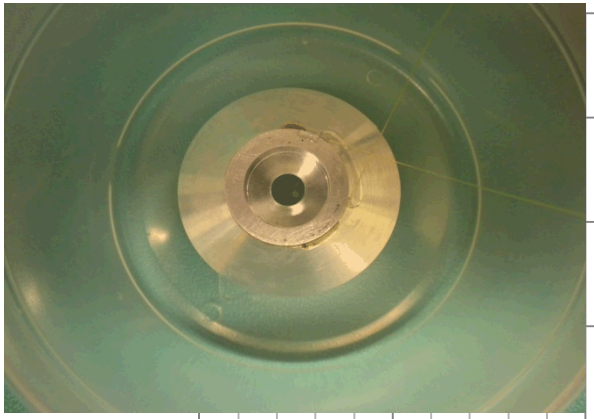
Chirped Fiber Mounted on Cone



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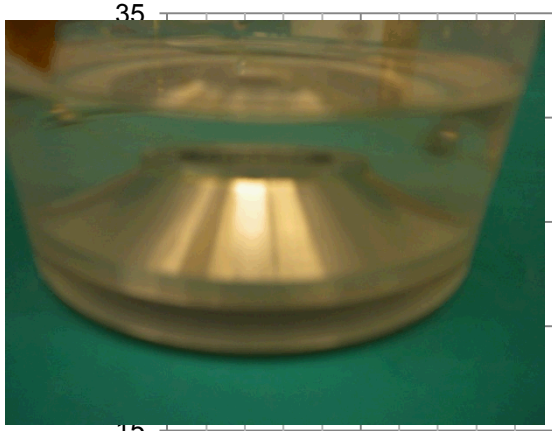
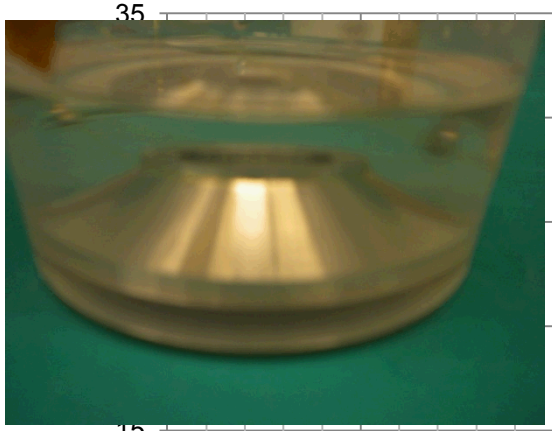


Shift of 2 nm = 2400με

Chirped Fiber Mounted on Cone



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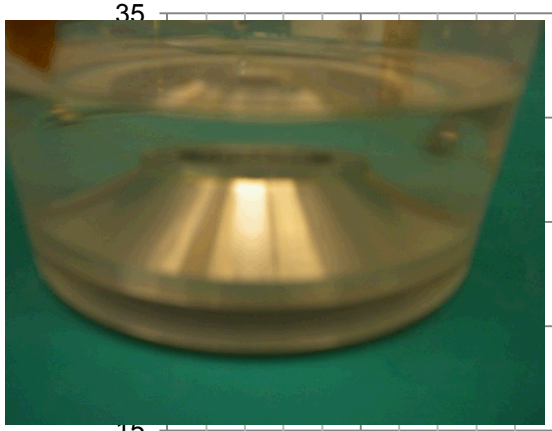

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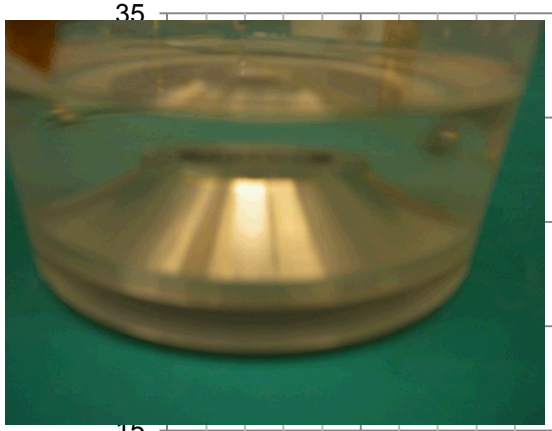

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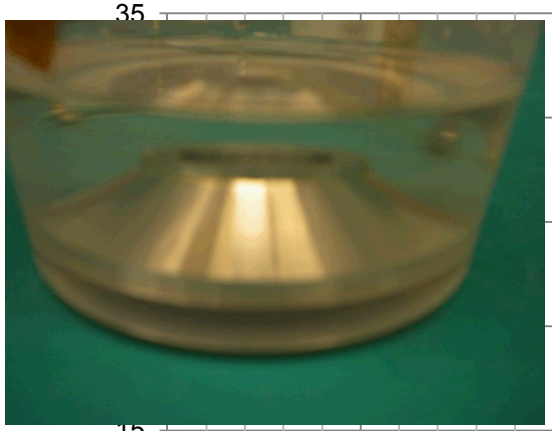

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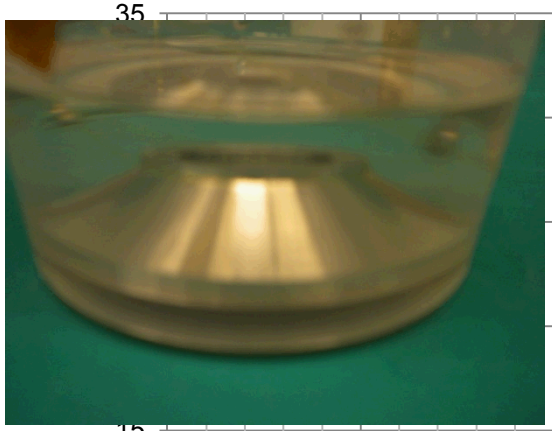

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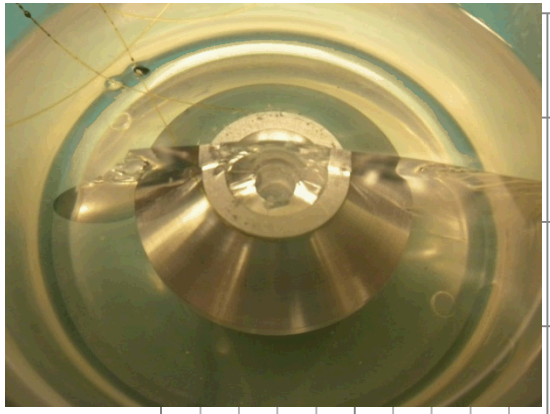

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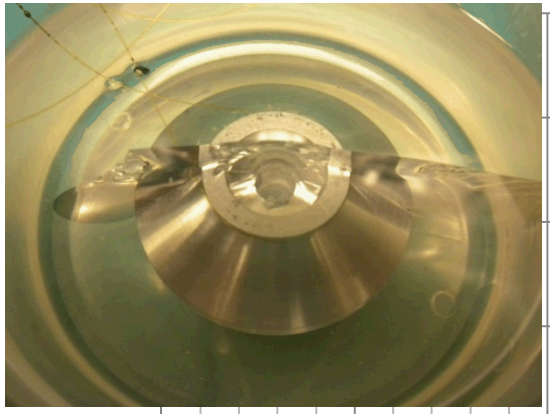

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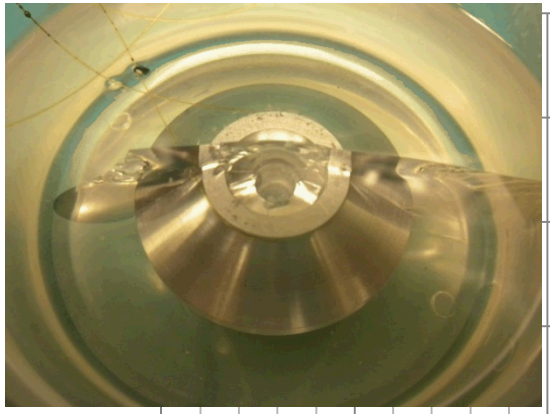

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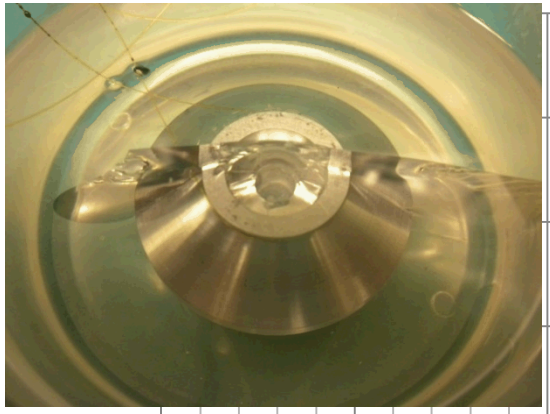

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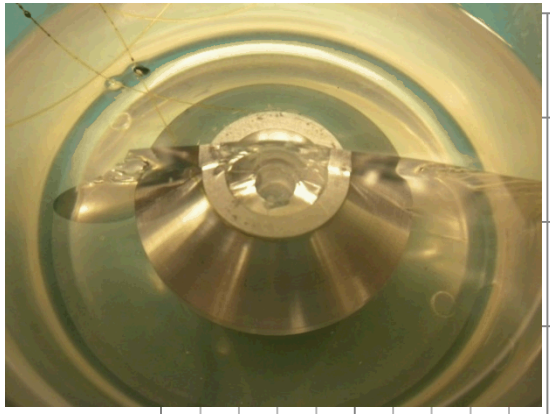

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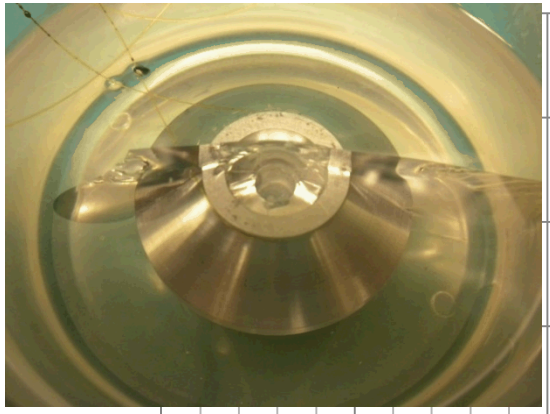

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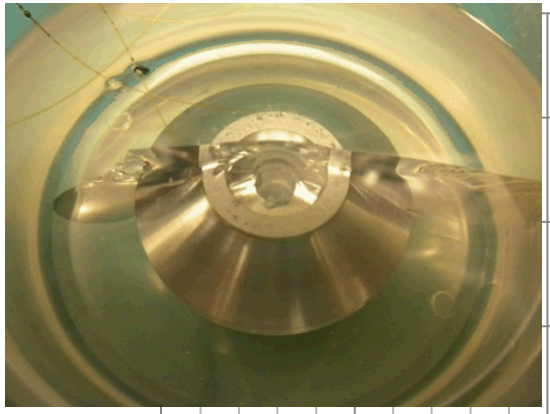

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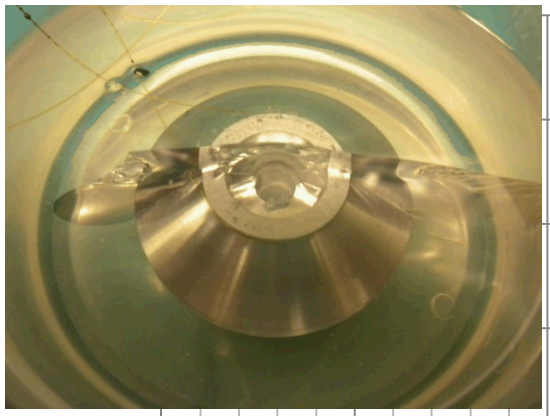

Effects of Thermal Cycling

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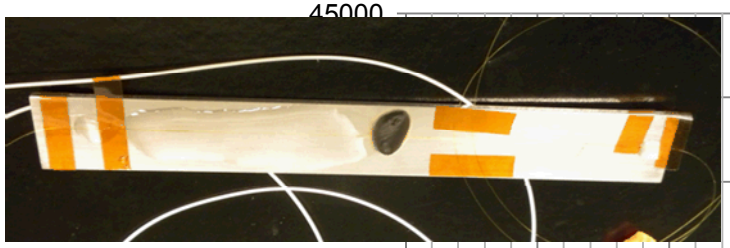

Shift of 2 nm = 2400με

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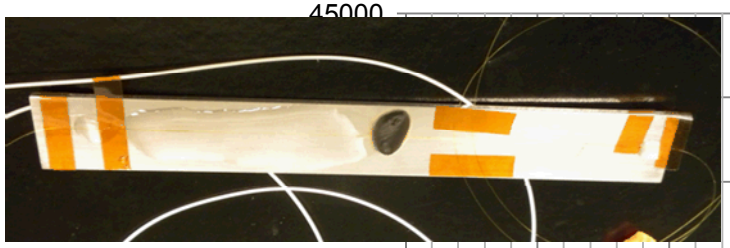
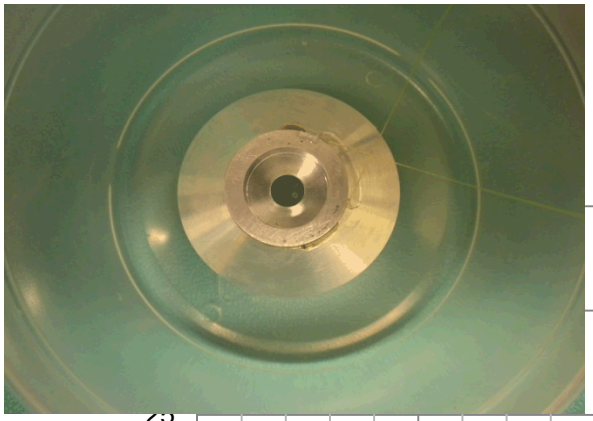


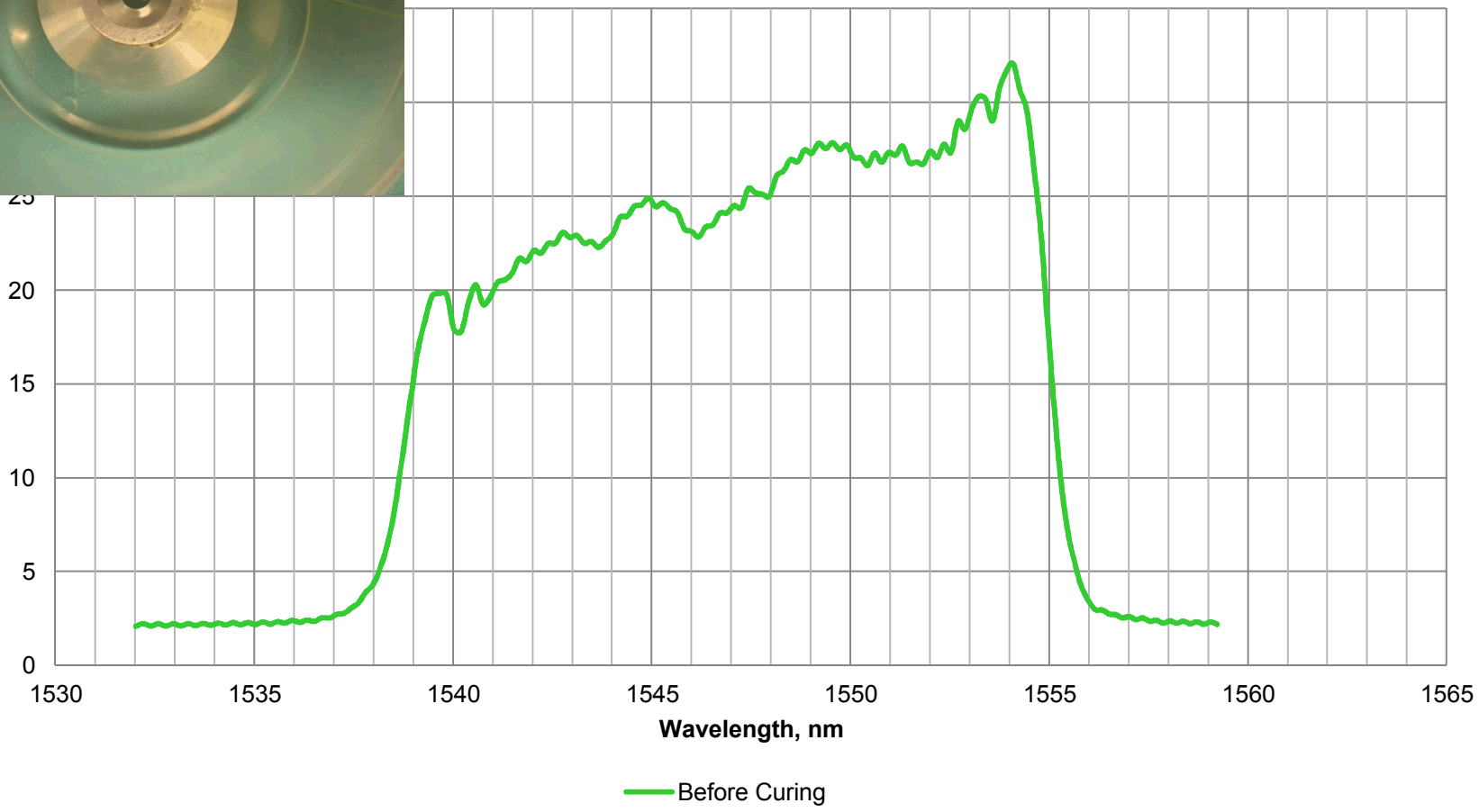
Shift of 3 nm = 3600με
Exposed Fiber

Shift of 5 nm = 6000με
Bonded Fiber

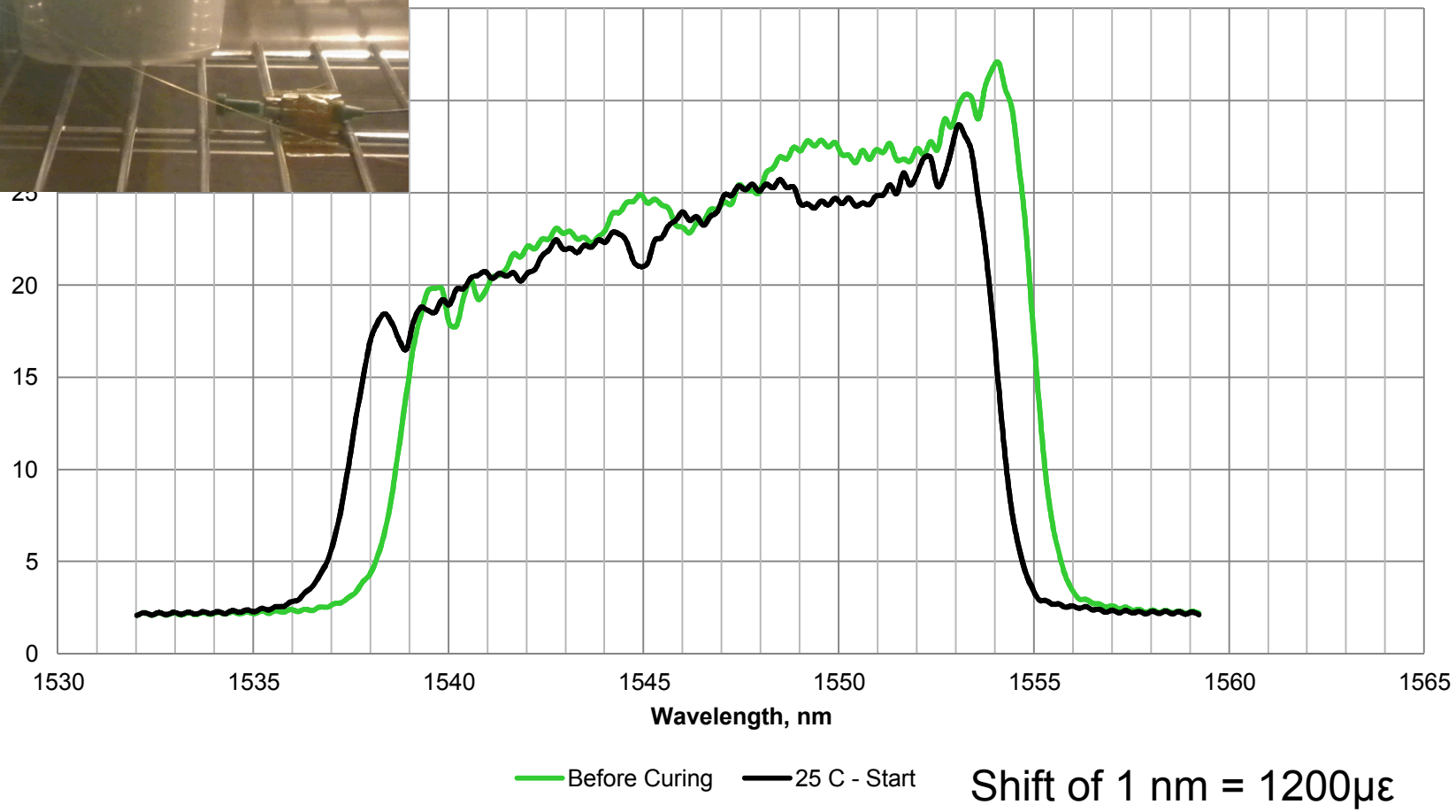
Shift of 2 nm = 2400με
Difference do to Epoxy

GMB Filled Cone



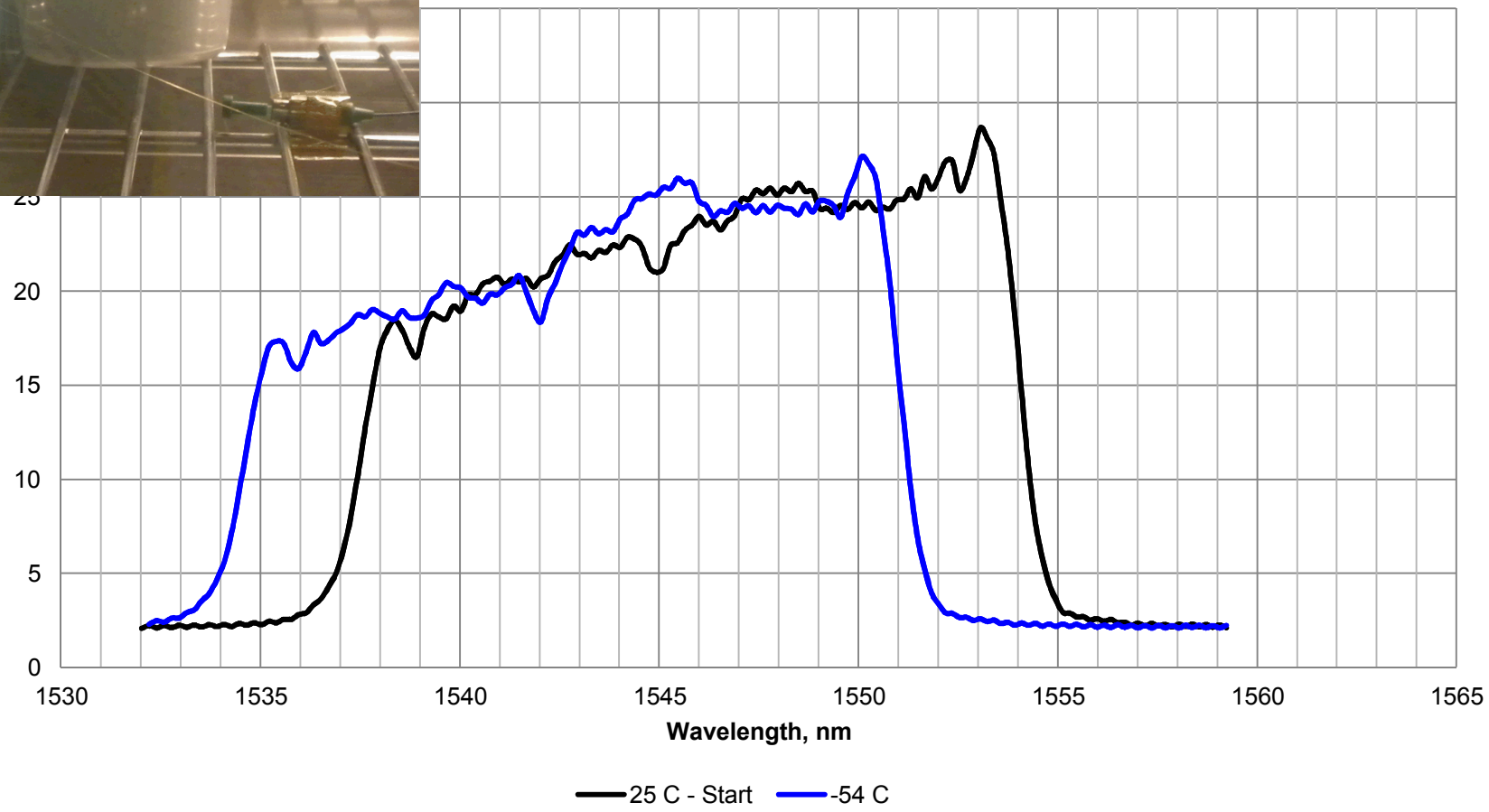


GMB Filled Cone

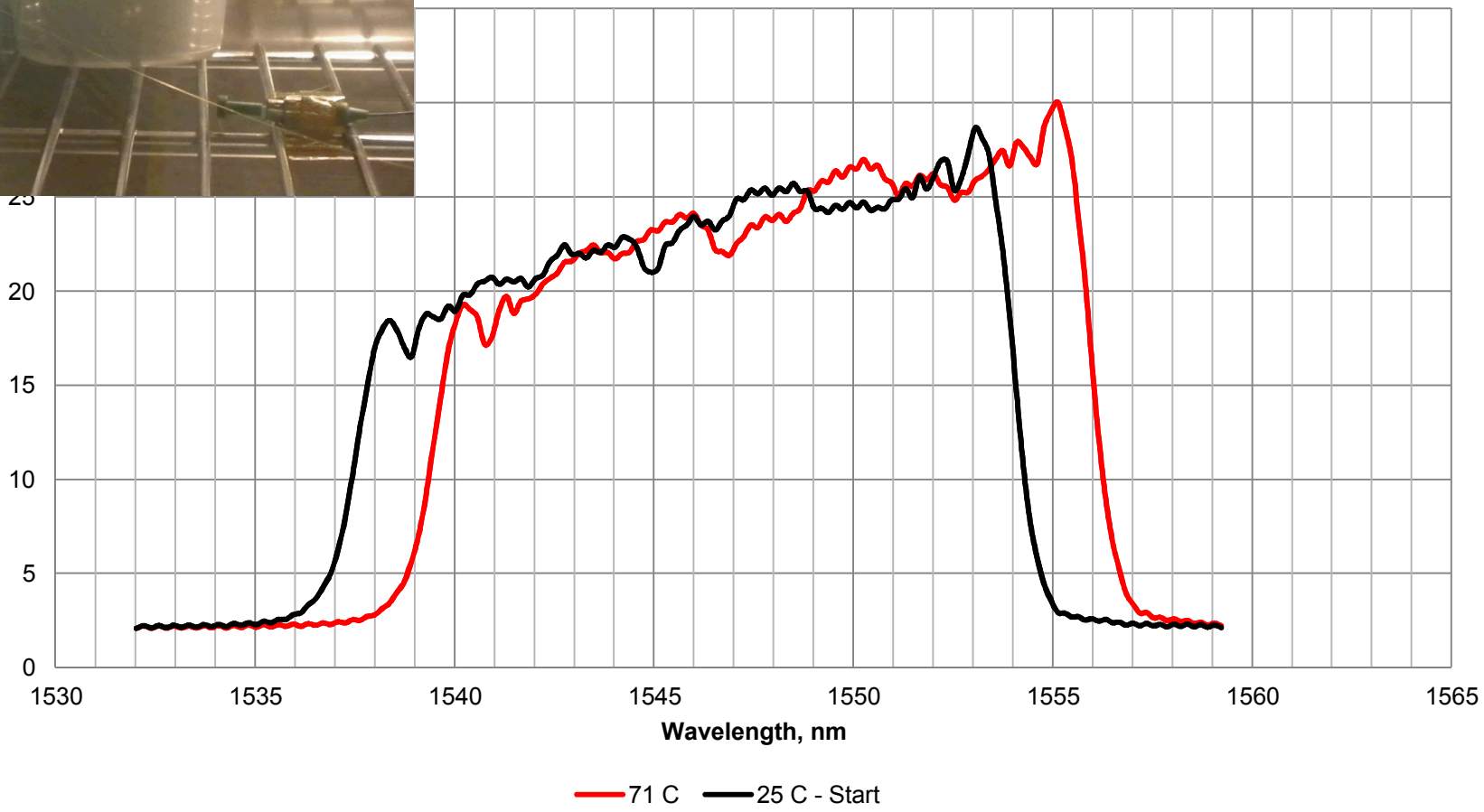


Shift of 1 nm = 1200με

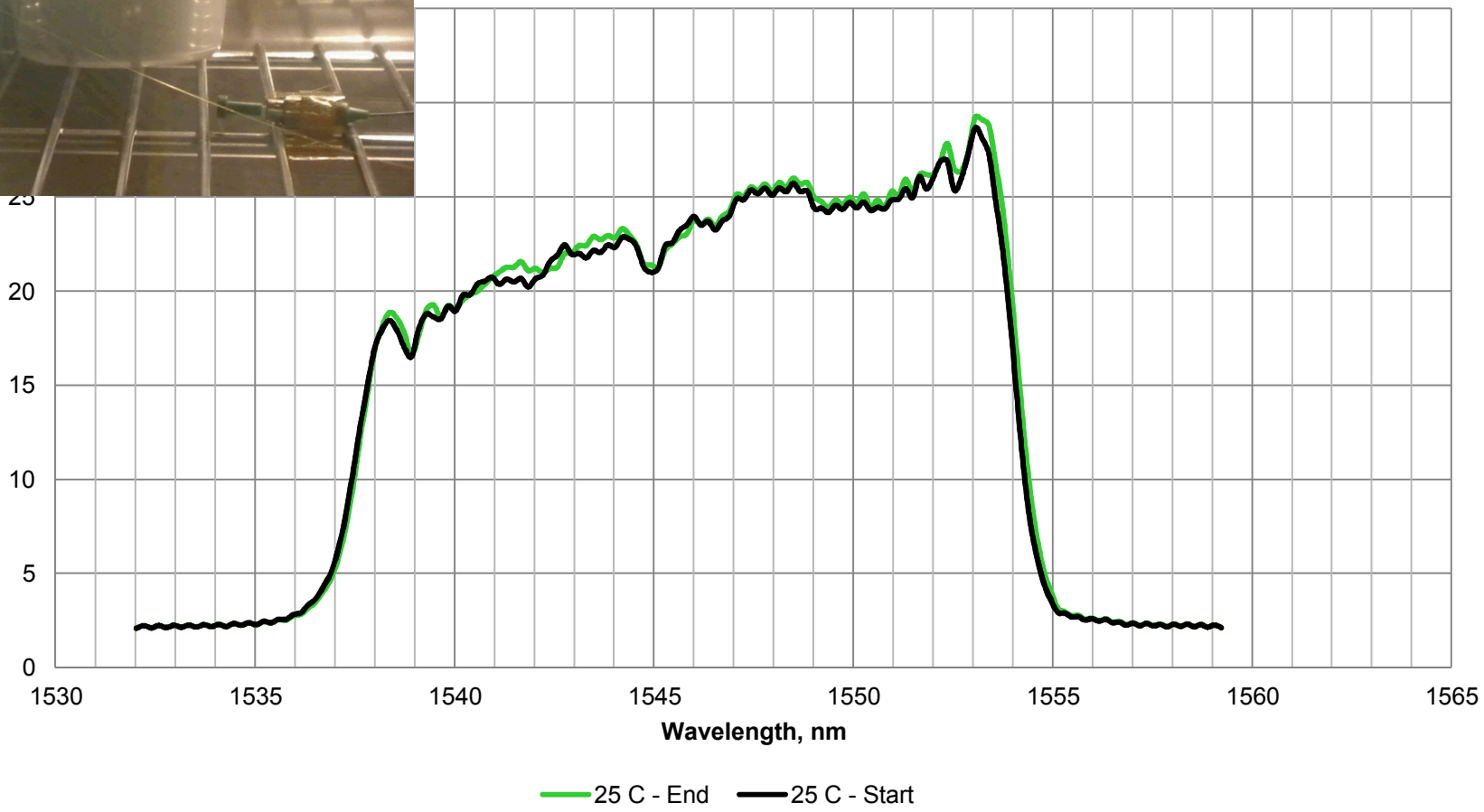
GMB Filled Cone



GMB Filled Cone



GMB Filled Cone



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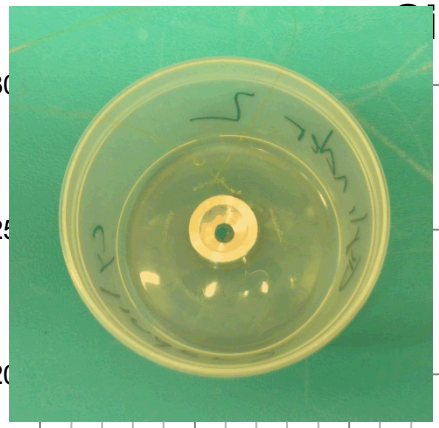
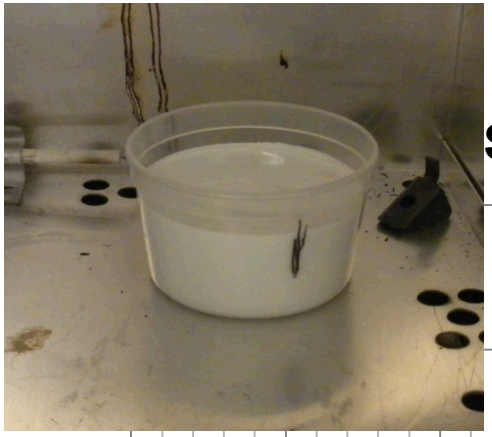
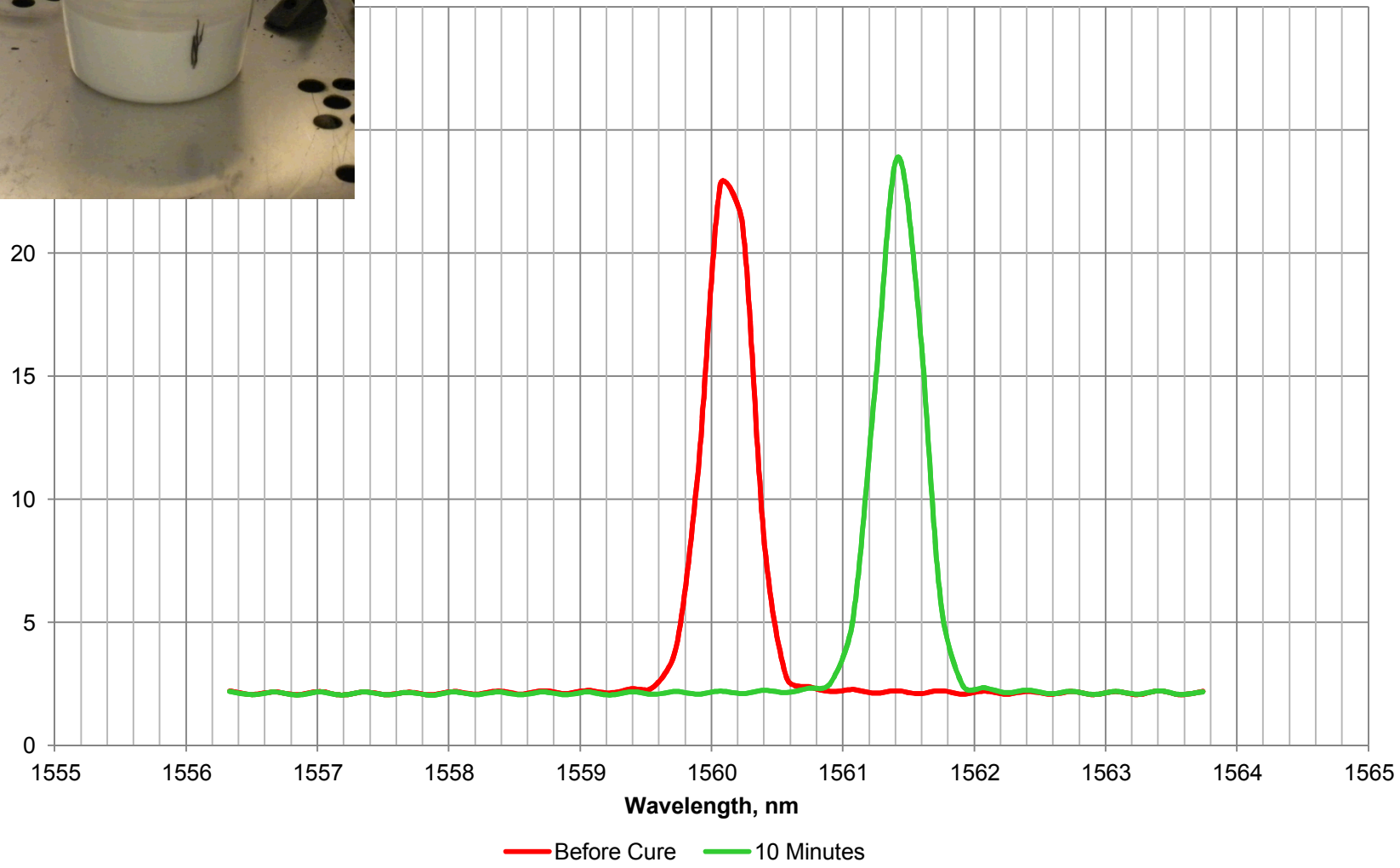
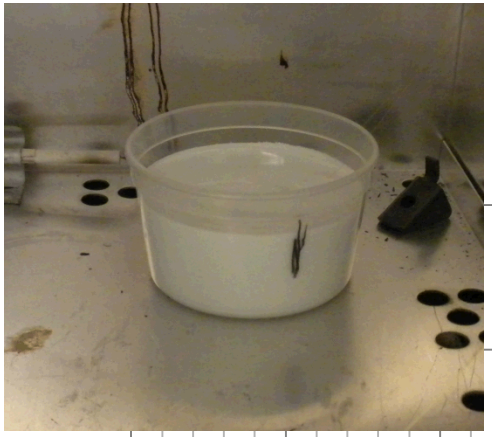
ingle Grating Curing on Cylinder



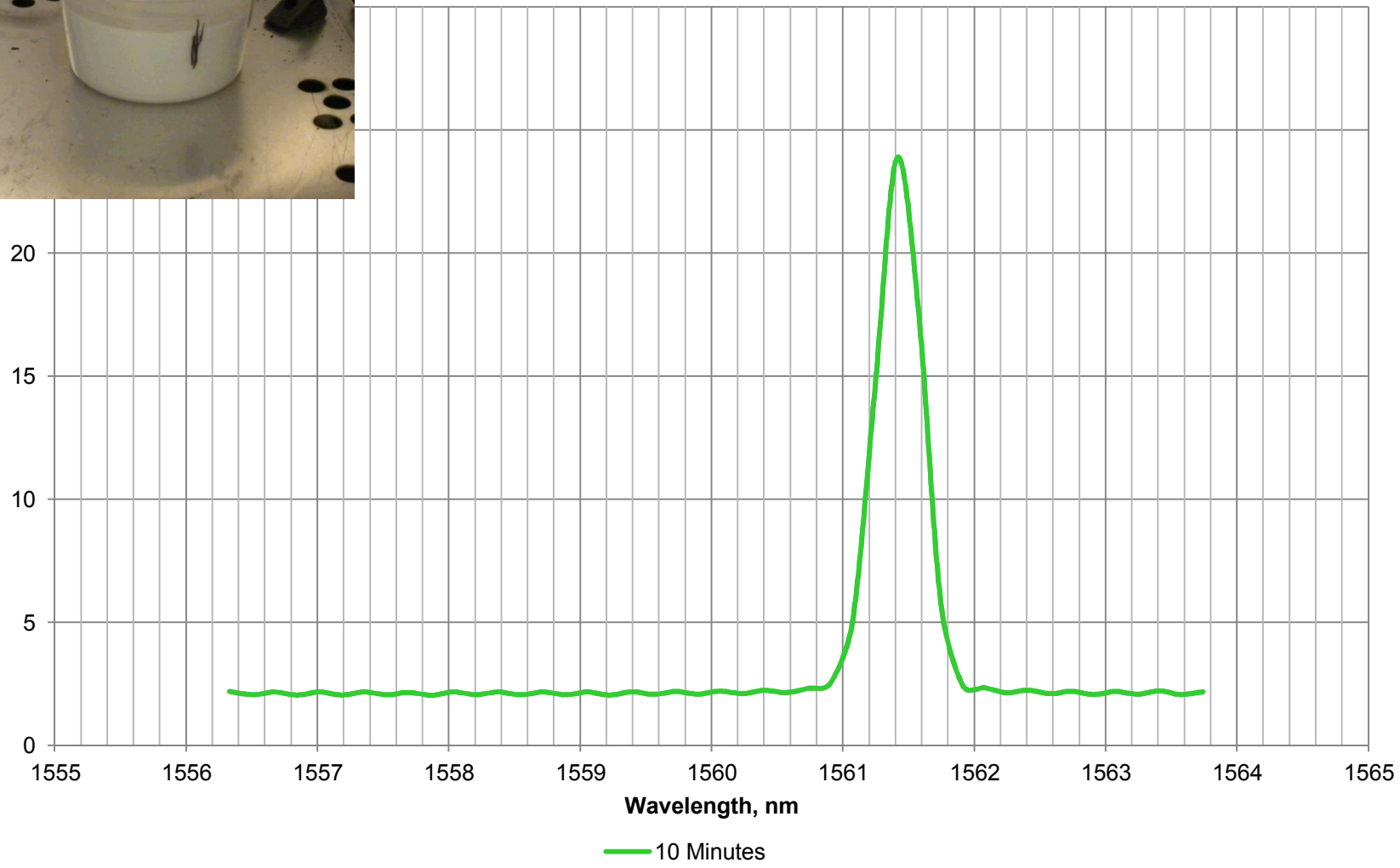


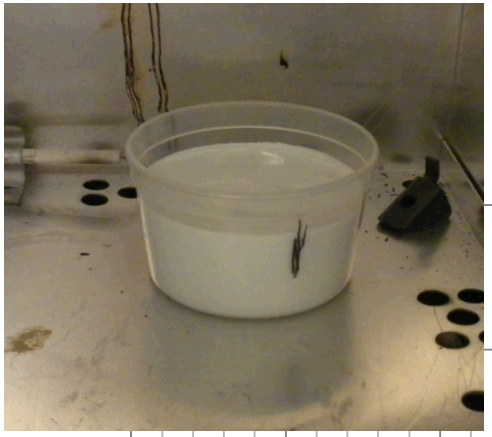
Single Grating Curing on Cylinder





Single Grating Curing on Cone





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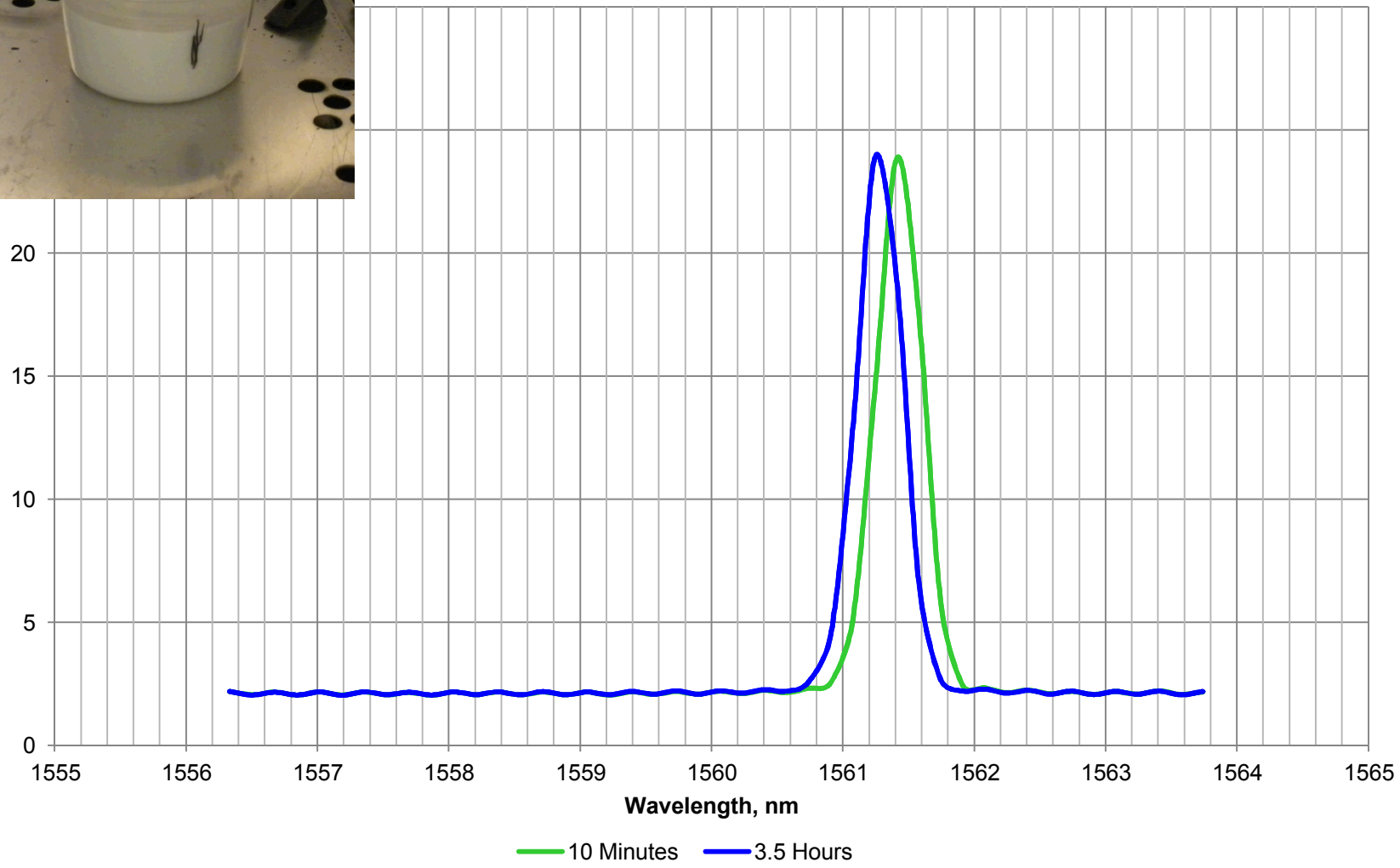

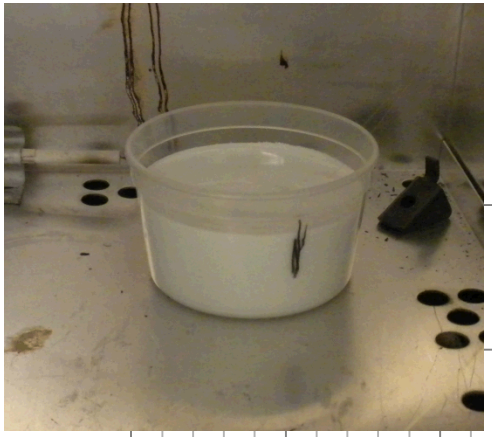

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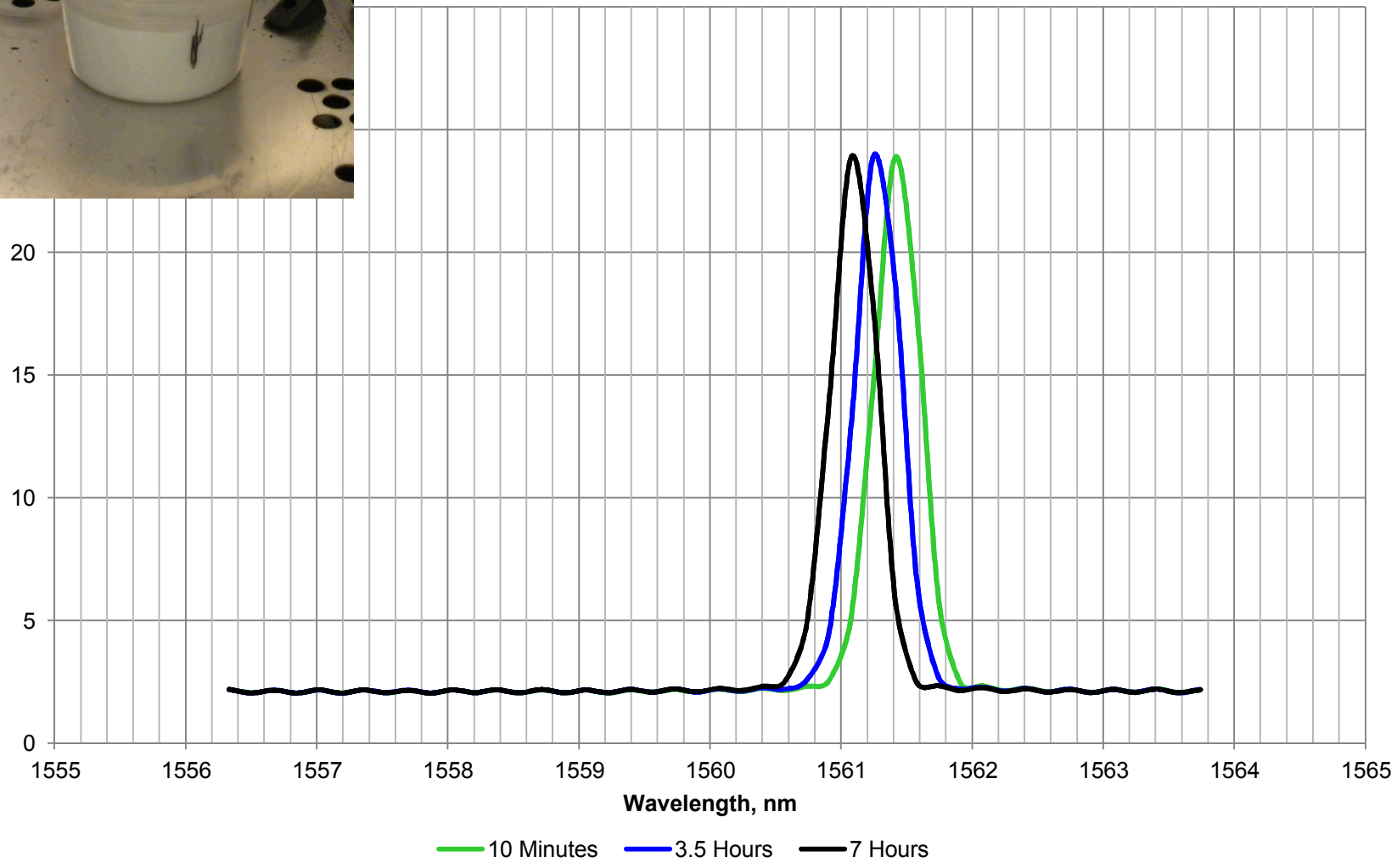

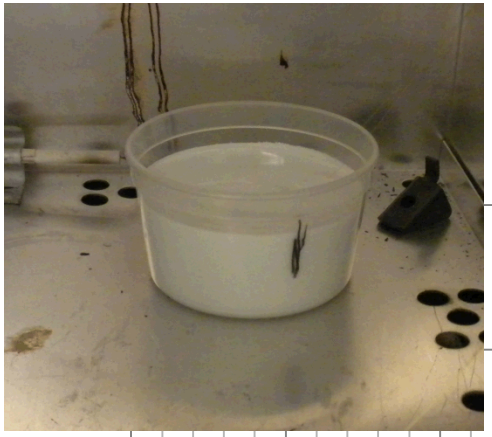

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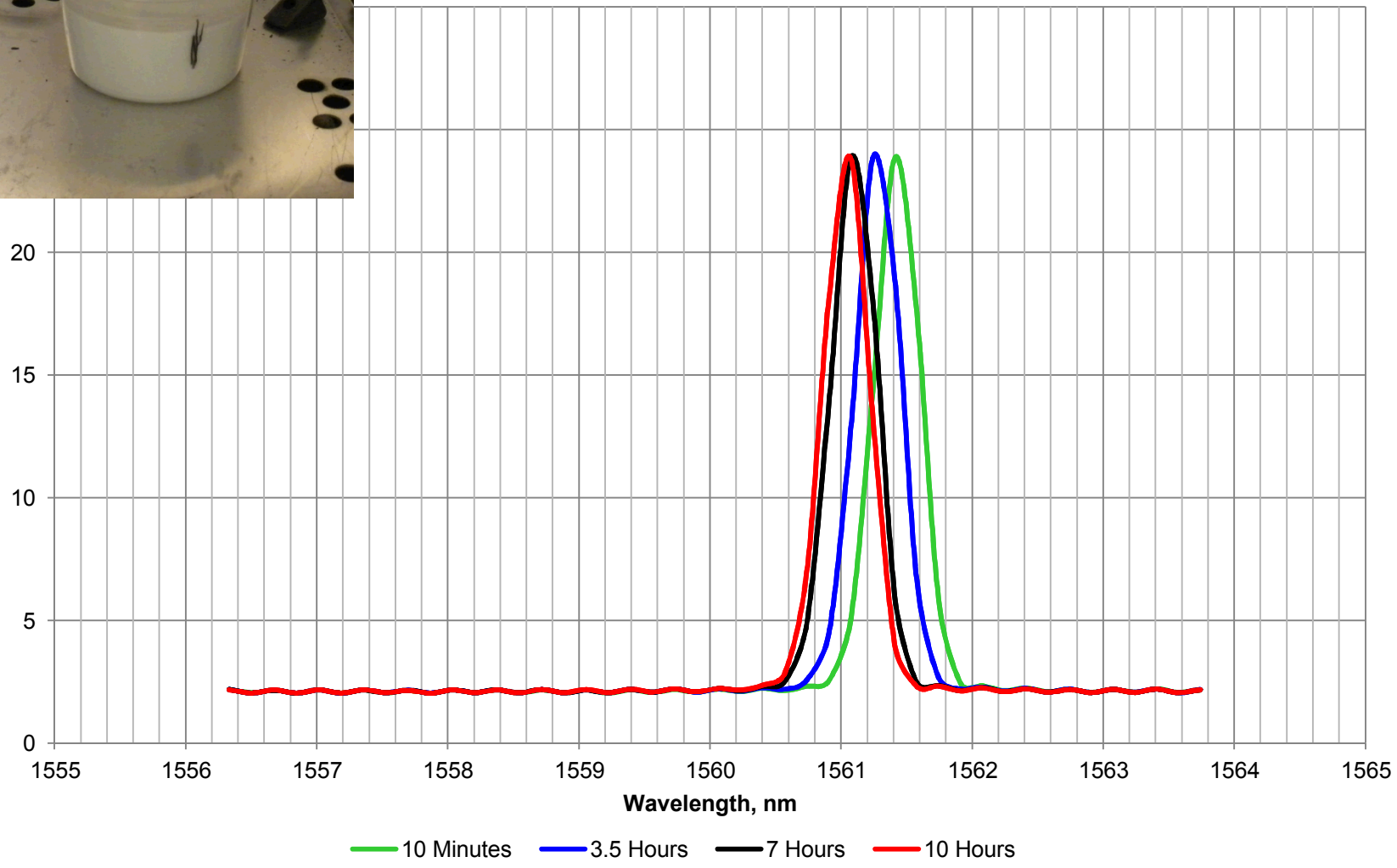

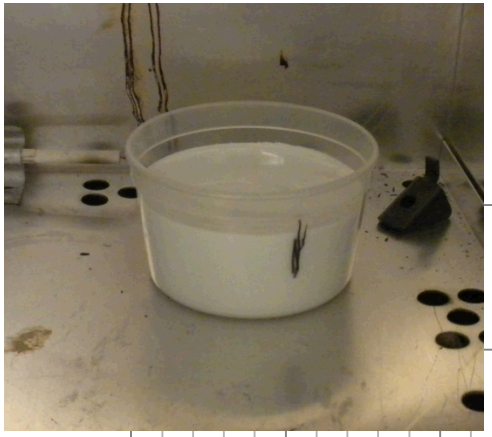

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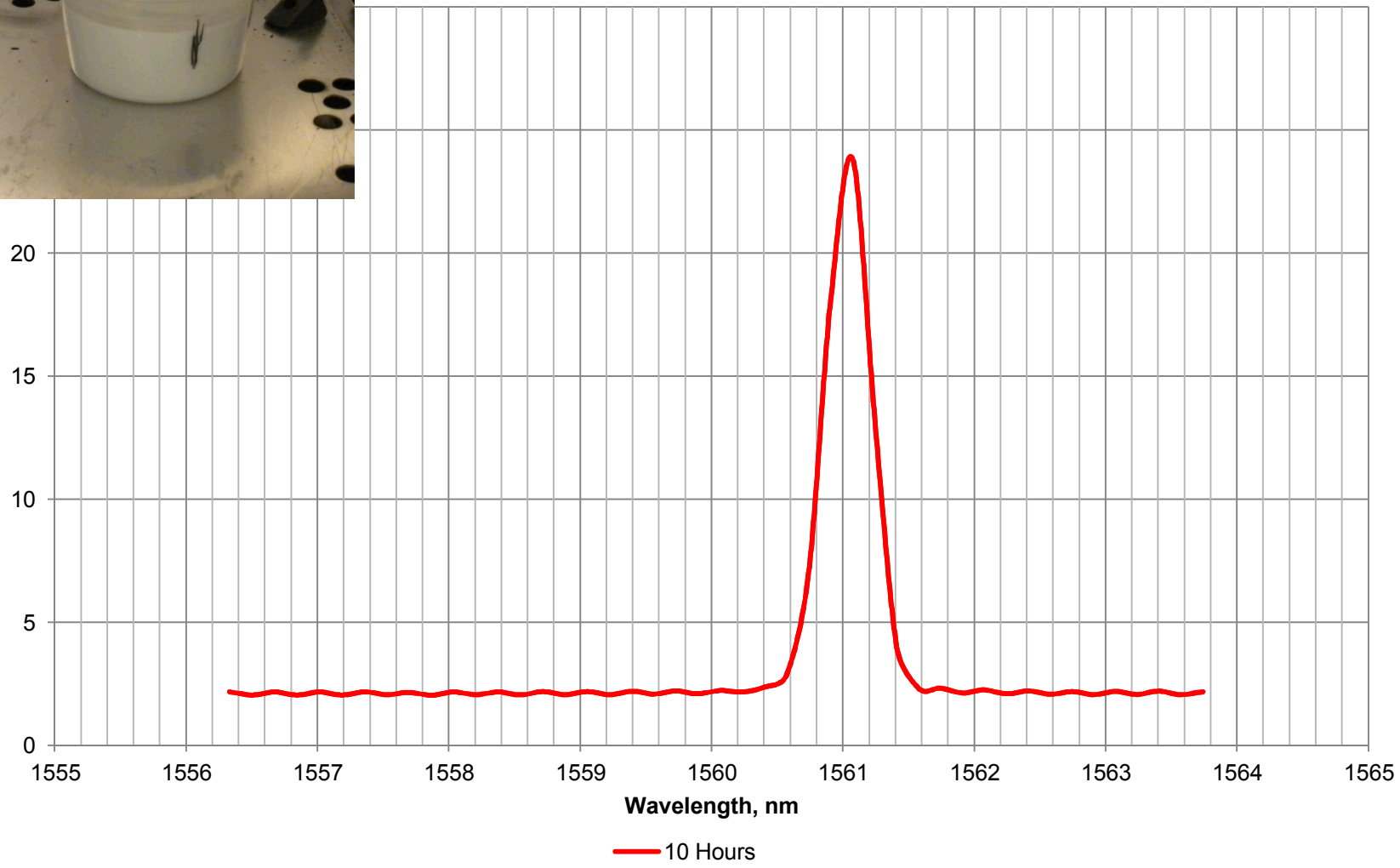

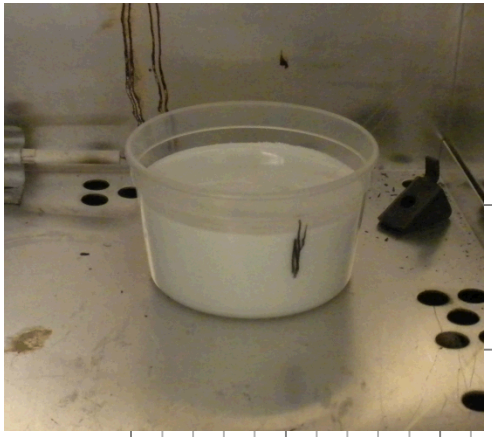

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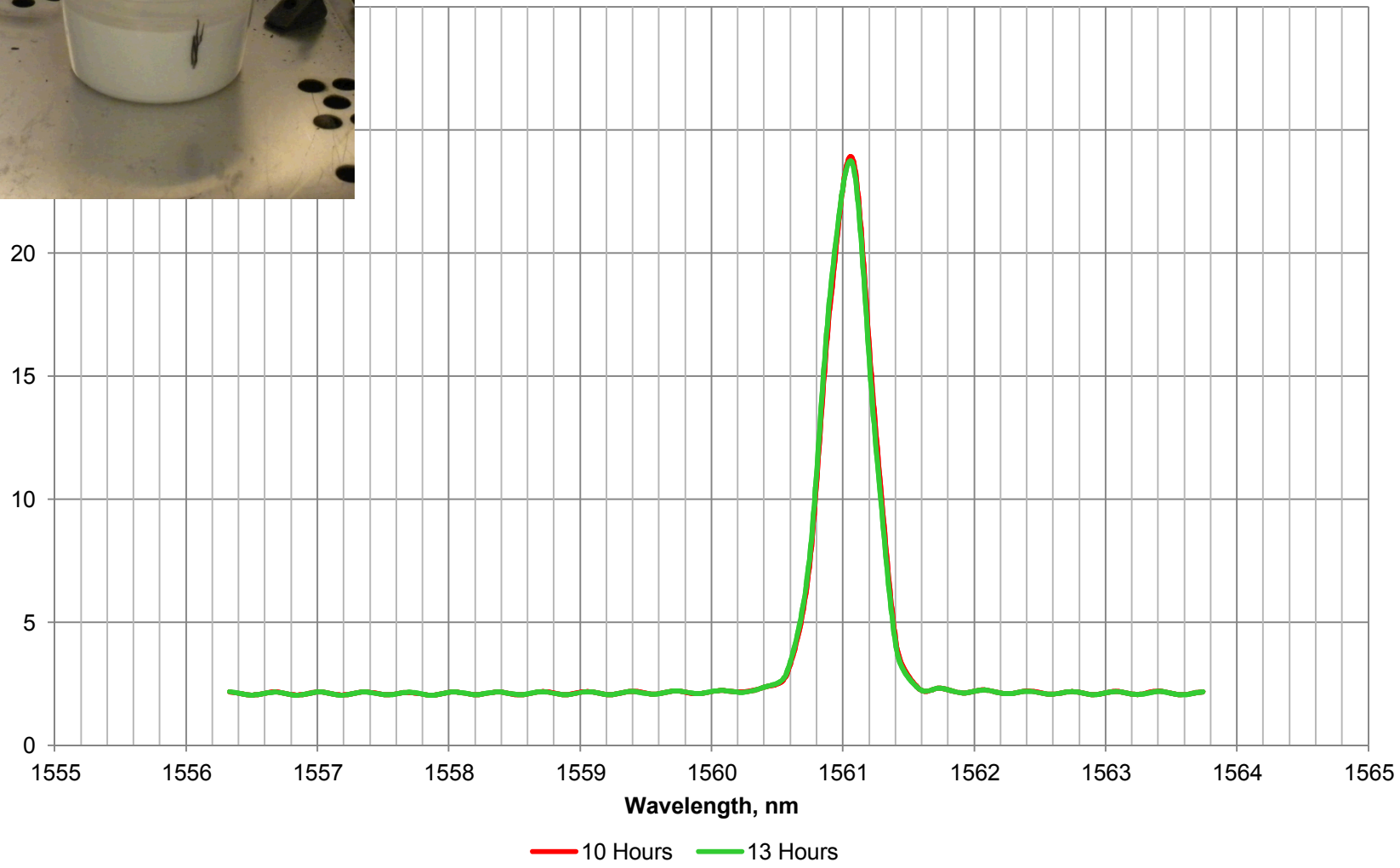

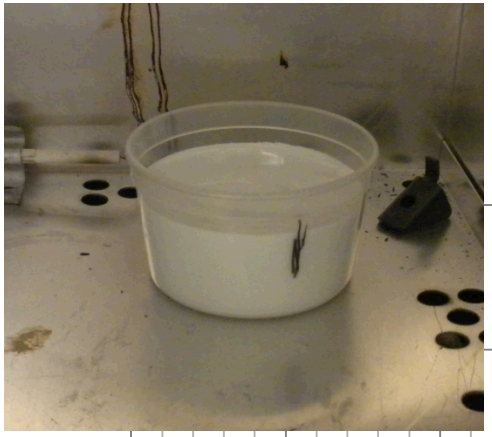

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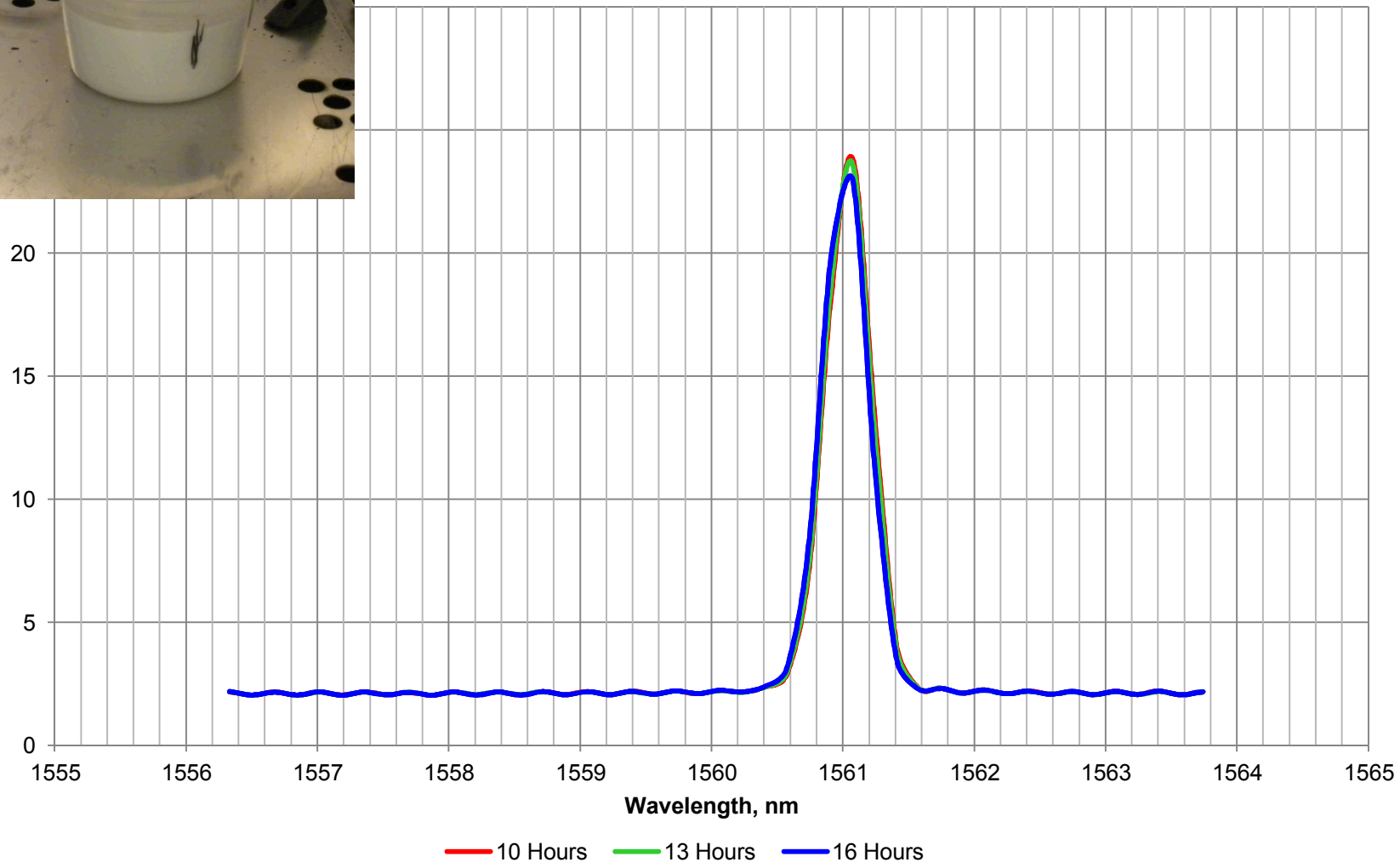

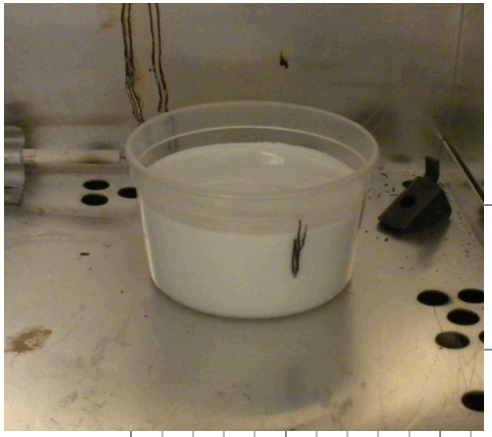

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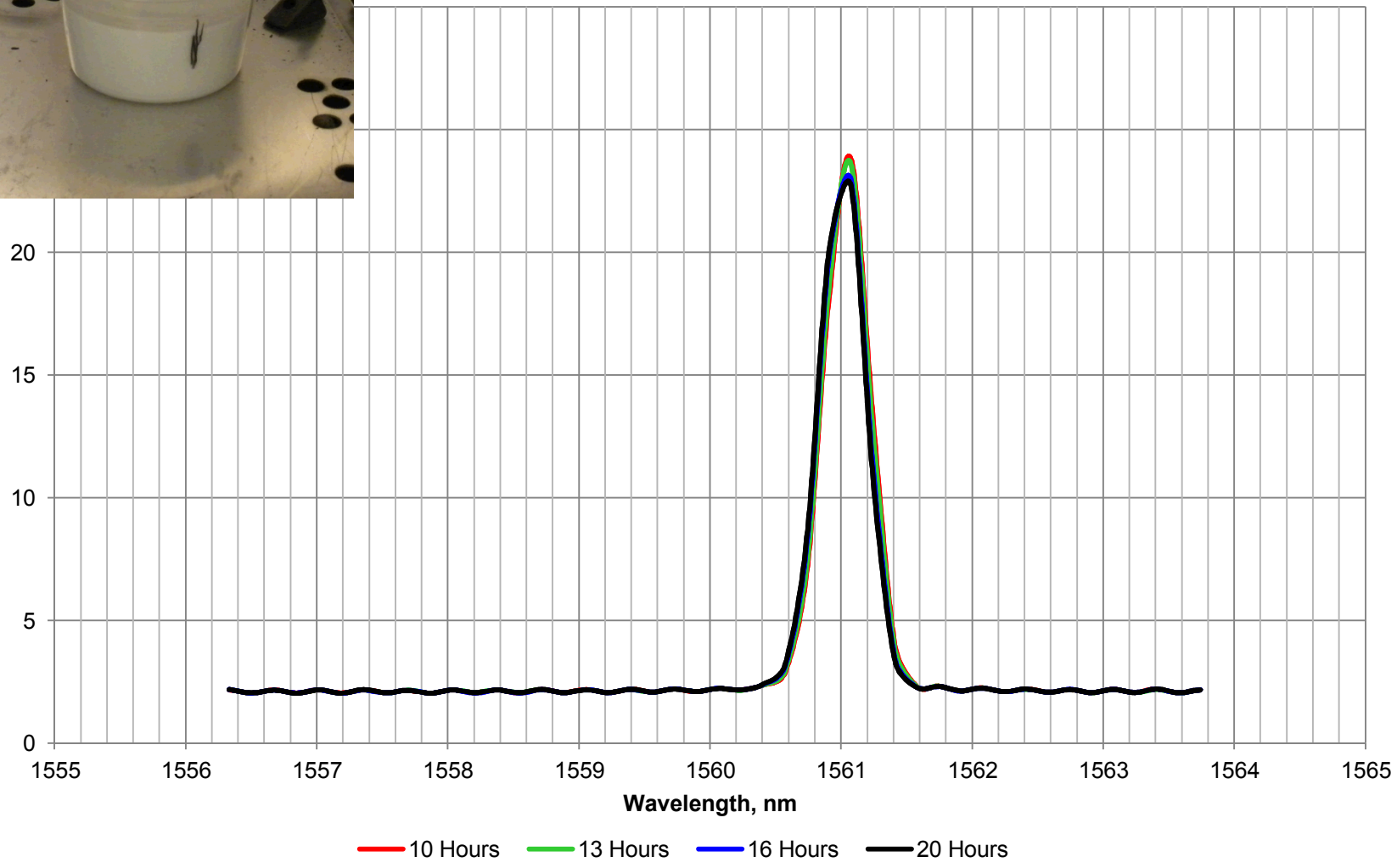

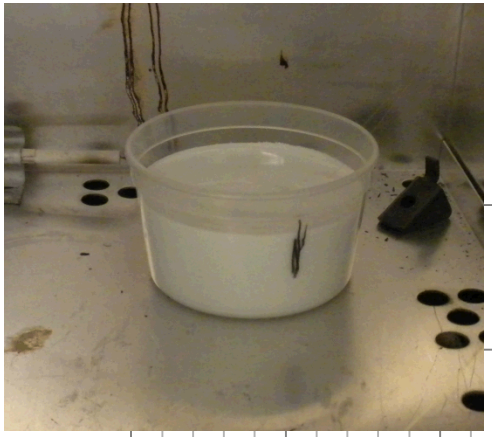

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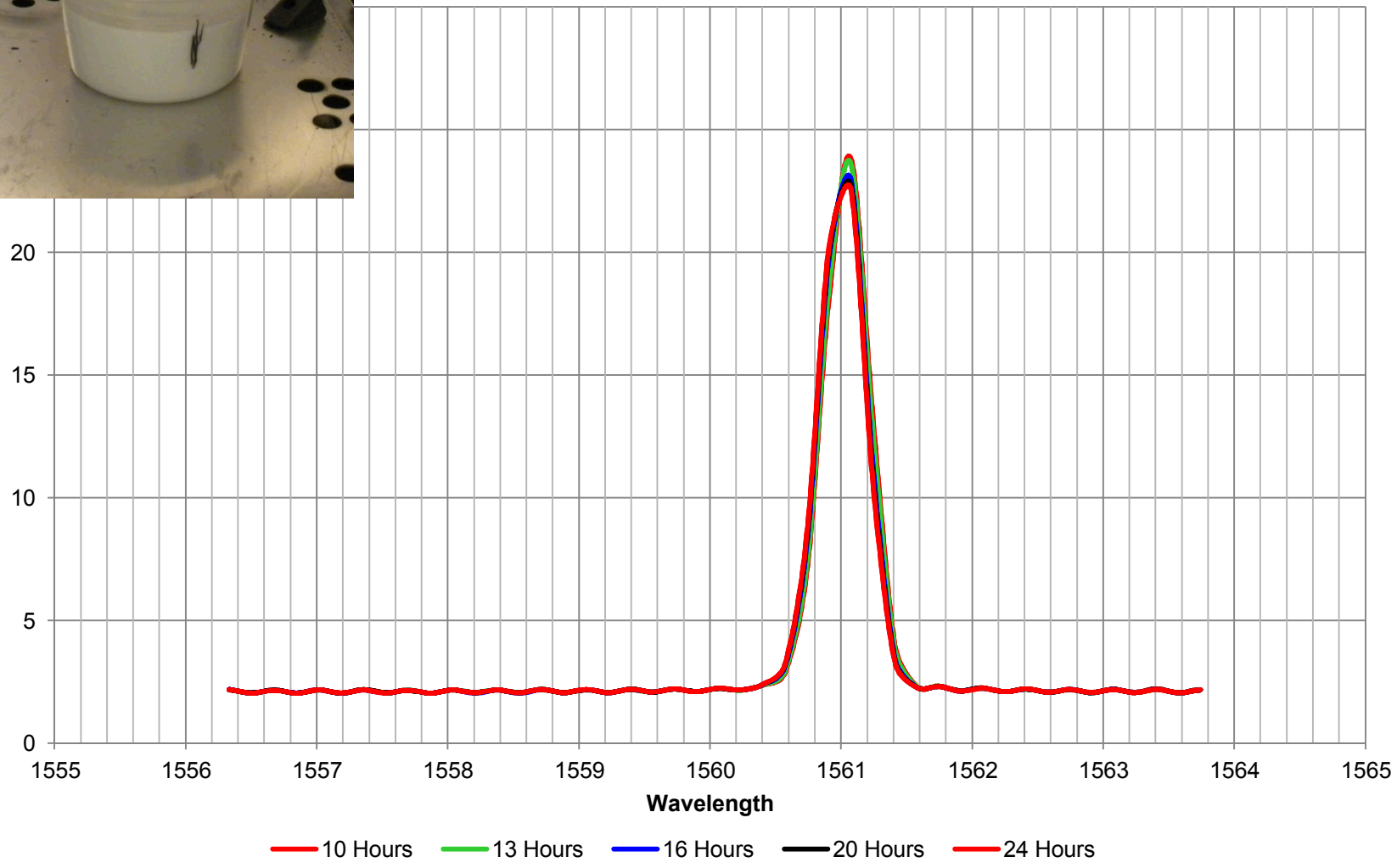

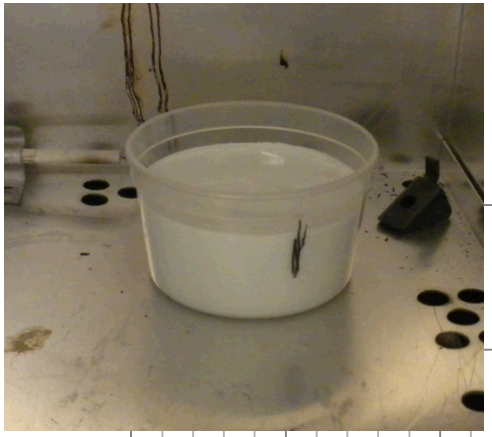

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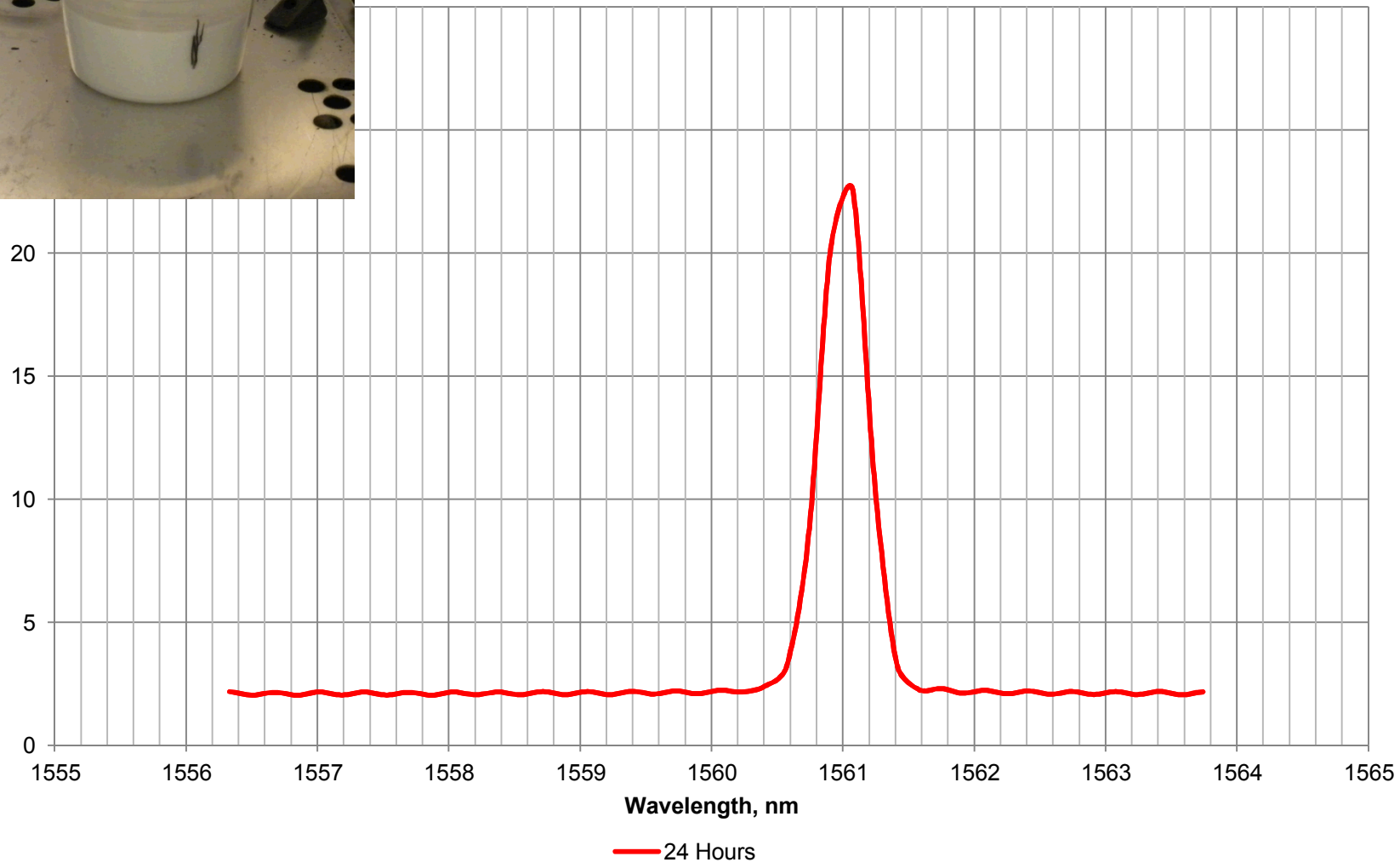

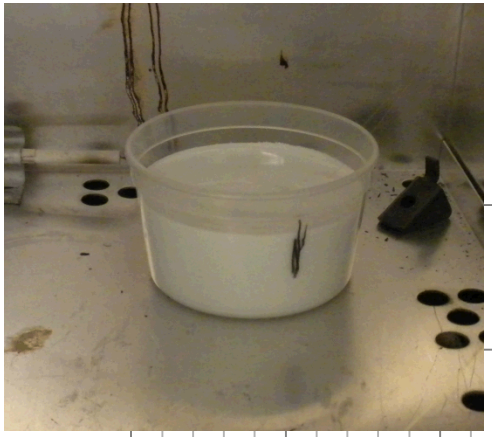

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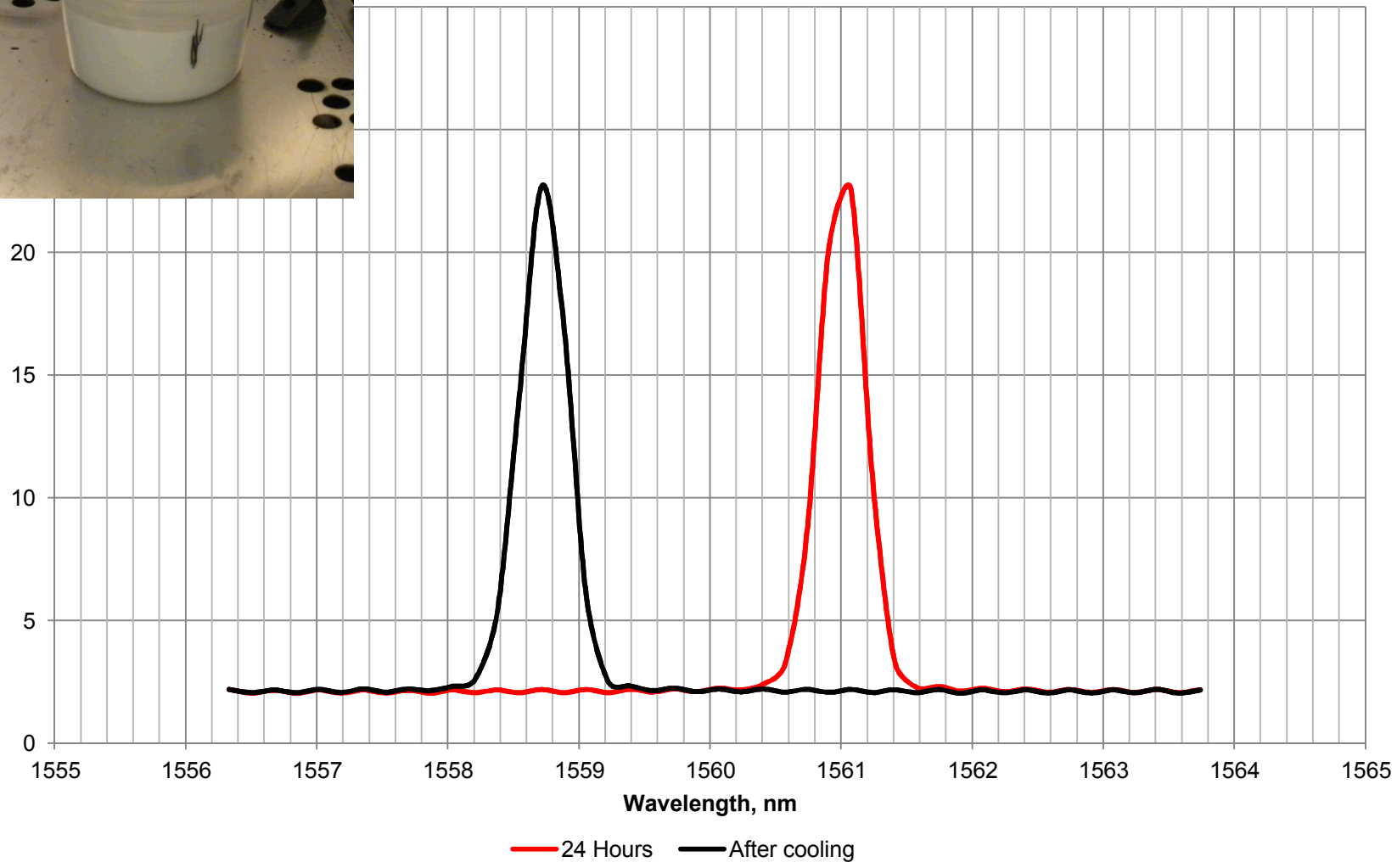

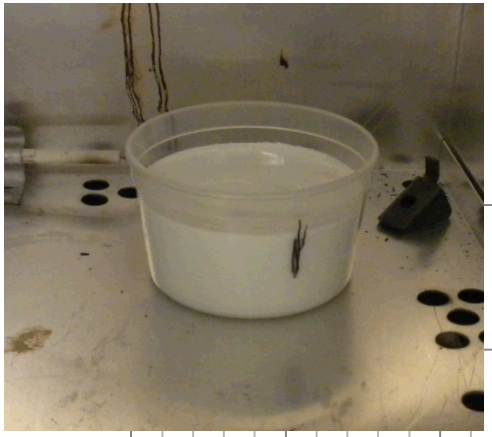

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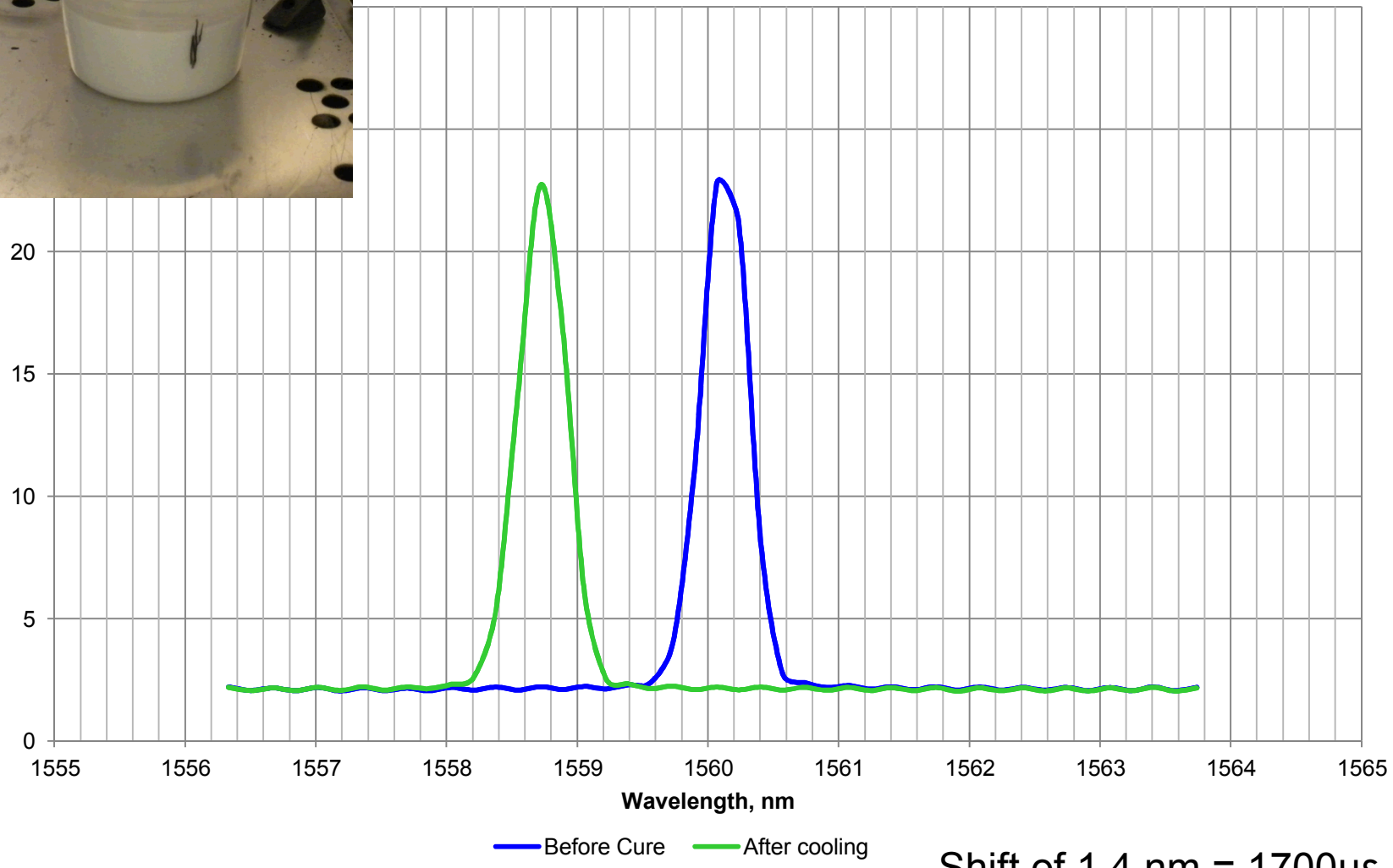
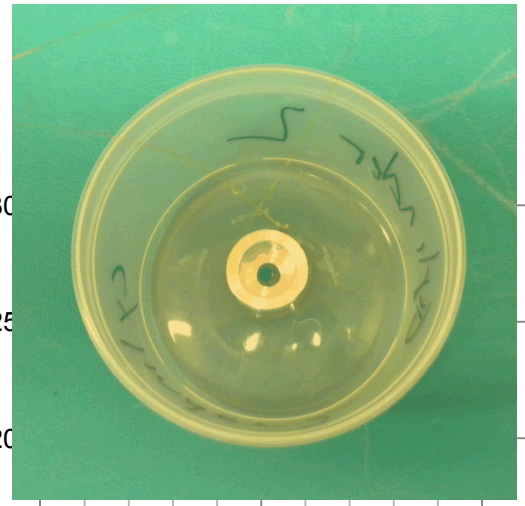
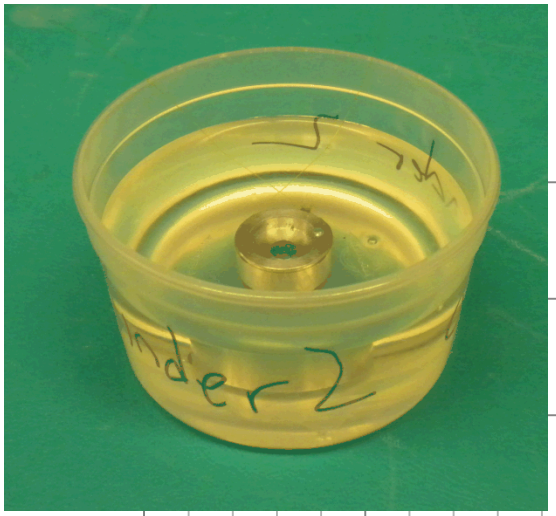


Shift of 1.4 nm = 1700με

Cylinder, No Additive



Cylinder, No Additive



Shift of 3 nm = 3600με

Other Results

- Age
- Silanes Improving Adhesion
- ADCB Testing
- Micro-indentation

Conclusions

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- Feasibility
- Resolution
- Effects of Filler
- Effects of different geometry
- Temperature stability
- Aging

Acknowledgments

- Roger Rasberry
- Garth Rohr
- Michele Denton
- Staci Dorsey
- Sandia
- USAF Academy